CONTROL

SPECIAL FEATURES

REGULAR FEATURES

RM

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TIMERS (EG) RELAYS

PROCESS TIMER

This unit embodies a synchronous motor wound for 240 V.A.C. and clutch mechanism, is provided with four change-over contacts rated at 6 amps. 240 V.A.C. and adjustable from 0.3 seconds to 6 hours.
Write for leaflet E.G. M.Z.11

NEW PRODUCT

SEALED MERCURY RELAY

This relay is the sturdiest yet designed, constructed almost entirely of steel and ceramic materials, without glass parts. It can be operated in any direction within 50° of the vertical line. This unit will withstand momentary short circuits without damage.
Write for leaflet E.G. S.R.12

NEW PRODUCT

MICRO SWITCH RELAY

The contacts of this Relay are totally enclosed and the coil operation is especially constructed to operated on A.C. supply, the unit can be mounted in any position, Contacts are rated at 6 amps single, double and triple pole change over.
Write for leaflet S.24 M.S.

OTHER PRODUCTS

ENGEL & GIBBS LTD

WARWICK RD · BOREHAM WOOD · HERTS · ELSTREE 2291 (5 lines)

ELECTRICAL SWITCHGEAR MANUFACTURERS

CONTROL
PUBLISHERS COLUMN

FULL STEAM AND NEW SKIPPER

This issue of CONTROL is the first normal one since the printing dispute. We say 'normal,' but a printing dispute, like most disputes, has its aftermath, and last month's issue appeared very late. So our Production Department and our printers were set quite a task to produce this issue in time for the Farnborough Air Show. As you will see, it carries a full preview of the exhibition at Farnborough, and some other articles on aircraft and guided weapon subjects. From now on we trust our production troubles are over and that CONTROL will be reaching you regularly in the early part of each month.

There is one important change on CONTROL's staff we want to tell you about. Christopher Rivington, who has edited CONTROL since the first issue, has now left us to join the book-publishing firm of Blackie & Son. We wish him good luck in his new post, and we welcome Arthur Conway, who succeeds him and will be editing CONTROL from the October issue onwards. He joins Rowse Muir from Atomic Power Constructions, and he has had previous editorial experience on the staff of *The Engineer,* and previous control experience with BISRA and De Havilland's. Conway is a qualified mechanical engineer with an excellent knowledge of automatic control in theory and practice, and we count ourselves very fortunate in obtaining his services, to succeed someone who has given CONTROL a good start. We look forward to publishing future numbers of CONTROL with even better editorial pages than before.

LETTERS TO CONTROL

Sir!

The Editor welcomes correspondence for publication.

Laplace simplified

SIR: In your report by Dr. G. D. S. MacLellan
on the Conference on Control Education at
Cambridge (May, p. 109), it was implied that
students experience difficulty with Laplace trans-
form techniques and that lack of knowledge
thereof only precludes the reading of a few
American textbooks. I believe the former to be
due to the lack of application of simplifying tech-
niques and the latter to be erroneous. Very few
British or American textbooks, particularly re-
cent works, do not use Laplace transform
methods.

Laplace transform methods provide a conveni-
ent means of introducing the important concept
of a complex frequency, and allow simplifica-
tions in obtaining transfer functions, transient
and frequency response in design in the ' p plane,'
including the work of Bode, Evans and others.

Perhaps I might offer a few constructive sug-
gestions on simplified presentation methods. The
transform of e^{-at} is readily established, from
$\int_0^\infty e^{-pt} e^{-at} dt$ as $1/(p + a)$ and hence $\mathcal{L}e^{j\omega t}$ as
$1/(p + j\omega)$ giving $(p - j\omega)/(p^2 + \omega^2)$. Taking real
and imaginary parts of $e^{j\omega t}$ and of this transform,
we have $\mathcal{L}\cos \omega t = p/(p^2 + \omega^2)$ and $\mathcal{L}\sin \omega t$
$= \omega/(p^2 + \omega^2)$. Also $\mathcal{L}e^{-at}e^{j\omega t} = 1/(p + a - j\omega)$
replacing a by $a - j\omega$; this gives $(p + a + j\omega)/$
$[(p + a)^2 + \omega^2]$. Proceeding as before, we find
$\mathcal{L}e^{-at}\cos\omega t = (p + a)/[(p + a)^2 + \omega^2]$ and
$\mathcal{L}e^{-at}\sin \omega t = \omega/[(p + a)^2 + \omega^2]$. Putting $\sinh \omega t$
$= -j \sin j\omega t$ and $\cosh \omega t = \cos j\omega t$ gives sinh,
cosh and exponentially multiplied forms. Thus
nine of the most important transforms are estab-
lished from one integration: most textbooks de-
vote several pages to these by deriving each inde-
pendently.

The impulsive function $\delta(t)$ is readily estab-
lished as a narrow pulse of time duration ε and
height $1/\varepsilon$ where $\varepsilon \to 0$. This clearly has unit area,
giving $\mathcal{L}\delta(t) = 1$, and provides the simplest ex-
pression for a forcing function; so that the im-
pulse response, being the inverse transform of
the transfer function, is easily obtained. Since an
impulse is the time derivative of a step function,
the step response will be the time integral of the
impulse response. A further simplification can be
effected by using the error/output transfer func-
tion instead of the output/input. This usually re-
duces the number of partial fraction coefficients
by one.

Wimbledon Technical College   N. G. MEADOWS

● **Dr. MacLellan comments:**

*' I welcome Mr. Meadow's interest and his discus-
sion of teaching problems and methods. In my
experience the algebra involved in the application
of Laplace transform techniques causes the
mathematically inclined student little difficulty,
though the significance of what he is doing may
well worry him. However for understanding
elementary control theory there is little of educa-
tional value in learning how to use tables of
transforms, or even how to derive them. When
emphasis is being laid on the fundamentals of
automatic control, it seems preferable to carry
through the analysis in terms of ordinary differ-*

PAPER

POLYSTYRENE

G.E.C. Capacitors

Sir!

ential equations, with which the student is likely already to be familiar, aided by block and/or dependence diagrams and the operator $D = d/dt$.

A discussion of the solution of differential equations in terms of the complementary function and the particular integral leads simply and directly to transient and frequency response and, if required at a more advanced stage, to the representation of system characteristics in terms of poles and zeros.'—EDITOR

0·78 not 0·80

SIR: May I point out a small numerical mistake in Data Sheet 9, by Dudgeon and Rowe (CONTROL, March 1959, p. 77). The value of optimum damping ratio for 2% tolerance, stated in the table to be 0·80, is actually about 0·78. A ratio of 0·80 is rather the optimum for 1·5% tolerance. The above-mentioned remarks can be verified by simple calculation, but a glance at Fig. 2 of the Data Sheet is sufficient to indicate that there is some discrepancy between the graph and the table for values of tolerance between 1 and 3%.
Haifa, Israel   N. SHNEYDOR

The authors agree that there is a discrepancy in the values of tolerance between 1 and 3% and apologize for interpolating from the graph where calculation would have been more precise. The graph has suffered somewhat by being reduced for reproduction, but the values of settling time given in the table are correct.—EDITOR

Dependence diagrams

SIR: As a comment on Mr. Bhatt's letter in your April issue, I wish to emphasize further the importance of these methods in teaching and studying various physical phenomena—other than servo systems—in which a scheme of dependence in a cause-effect sequence can be recognized, as for example the familiar problem of a mass on the end of a spring.

I have found that the greatest difficulty experienced by students is appreciating mathematically a physical system; block diagrams form the perfect link for correlating the two, and thus more fully appreciating both mathematics and system. Further the rules for reduction allow a purely mechanical transition from the initial diagram to the system transfer function, and the setting up of a block diagram forces one to think the system out in detail.
University of New South Wales   E. C. HIND

No control by correspondence

SIR: Unfortunately I am a long way from my mathematical education, and a very raw beginner in the control field, and would therefore appreciate any advice you can provide regarding correspondence courses available in the UK, which would bring me up to date on control engineering from A to Z, so that I can use more completely the articles in your publication.
Brisbane, Queensland   R. B. FARR

There are so far as we know no correspondence courses on control engineering provided in this country. See the reply to a similar letter to yours published in the April issue this year, p. 61. You may care to approach one of the schools whose names we are sending you direct.—EDITOR.

CONTROL

Society tangle

IN Britain today the young control engineer faces a plethora of professional bodies that claim his attention. The Institutions of Mechanical, Electrical, Chemical, and Production Engineers, the British Institution of Radio Engineers, the Royal Aeronautical Society, the Society of Instrument Technology—the list could easily be extended. Like cures for rheumatism or methods of street lighting, the very multiplicity of societies catering for control engineers shows that none is wholly satisfactory for the job.

Most engineers join a professional society for the sake of the qualification it awards, for the opportunity of meeting other engineers of similar interests, for technical information provided through meetings, publications and a library, and for the chance of contributing themselves towards the well-being of their profession. At present the British control engineer who seeks high professional qualification clearly needs to become a corporate member of either the Mechanicals or the Electricals. (Membership of the Chemicals though of comparable status is probably not so useful to the control engineer.) But apart from qualification, neither the Mechanicals nor the Electricals provides fully what a control engineer looks for in a professional society. A glance at the year's programme of meetings, or half-an-hour in one of the two libraries, will satisfy a systems-minded engineer on this point, notwithstanding the growing interest in the subject by the Mechanicals, and their issue last year of a policy statement. Nor do we forget that the Electricals held an admirable and catholic convention on automatic control in 1947, whose proceedings still form an excellent reference.

So the keen control engineer finds it necessary to join one or more of the other societies according to his interests—societies which can offer him information and contacts not to be gained from Storey's Gate or Savoy Place.

This situation is not unacceptable to present professional control engineers, most of whom originally qualified as mechanical, electrical or electronic engineers. But the rising generation of control engineers will, increasingly, be trained in their subject from college days, and will rightly demand a qualification and a professional society wholly germane to it. A splinter society will inevitably appear, if the present professional services for the control engineer are not improved.

Two ways of doing this suggest themselves to us. The first lies in expansion of the SIT, a vigorous, successful and growing society, whose field, though biased towards process industries, comes nearer that of the control engineer than any existing society in Britain. Were it to award qualifications, change its name, broaden its scope to include more kinetic control, and start a library and other central services, it could then become the recognized institution of control engineering.

The second way is by a consortium of engineering societies, which would award its own central qualification in control engineering. This qualification would admit the control engineer to membership of any of the constituent societies (on special terms), to obtain the services he needed. We cannot here dilate on the theme of the ' generalist' as against the ' specialist' engineer, but the control consortium might be useful in introducing engineers of unusually broad outlook among members of specialized engineering bodies.

Of course a consortium already exists in the British Conference on Automation and Computation. But it is not a qualifying body and it includes many non-engineering societies. It is somewhat cumbersome, and its usefulness seems at present limited to exchanging 'diary' information between member societies and in seeing that Britain is represented at international congresses. Moreover the BCAC's failure to accept the BritIRE's application for membership shows that it is not as representative as it purports to be. We hold no particular brief for the BritIRE's control and computer activities but that institution clearly has as much right to be a member of the BCAC as many other member societies, and events like the Convention on ' Electronics in Automation ' should certainly be made known to members of BCAC societies. We suggest to the BCAC that it might now make amends for its petty behaviour by inviting the BritIRE to join it.

Whether the SIT, the consortium or another solution is eventually adopted, it should surely be worked out by collaboration among established engineering societies. In chemical engineering the Chemicals had a hard struggle for full recognition; in control engineering is it too much to hope that the major engineering institutions will give a lead rather than fight a future rearguard action—by beginning discussions now on the best form of society for professional control engineers?

Michael James, de Havilland Propellers'
Chief Systems and Electronics Engineer, demands
digital rather than analogue systems in

DIGITS FOR CONTROL

WHEN IS THE CONTROL ENGINEER GOING TO appreciate the great potentialities of digital as opposed to analogue systems? For unless he does recognize their advantages, and by his own application of digital techniques urges further development, we as a country are not going to stay abreast of international progress in automatic control.

The binary digit, or bit, either a 1 or 0, is one of the basic concepts in nature. It is a simple concept which provides certain advantages over analogue techniques.

Take cost for example. If it is specified that a measurement and control system should be to 1% accuracy, then all elements in the system must individually be even better than this figure. In analogue systems cost rises according to a steep exponential law as the demand for accuracy increases; for accuracies better than 0·01%, analogue systems are prohibitive in cost.

With a digital system, however, once a digital 'word' has been obtained which relates the value of the measured parameter in digital language, then there is no subsequent loss of accuracy no matter how much computation or inter-relation there may be. Accuracy in a digital sense is purely a function of word length. The cost of a digital system can, therefore, be based roughly on the cost per bit. Hence, to a first approximation, cost and accuracy are linearly related.

What of reliability? As control systems will of necessity become more complex, and the degree of unsupervised operation increases, reliability studies will begin to have real meaning. It must be remembered that overall reliability equals the product of the reliability of the components. Thus suppose a control system has 100 components each of 99% reliability, then the overall reliability will be 36·5%. The analogue device, as it becomes more accurate, is particularly susceptible to this sort of reliability fall-off, since the precision and complexity demanded of it have an adverse effect on component life. Simplicity is necessary for reliability but, with an analogue system, accuracy and complexity of a control application may not allow this. However,

what could be simpler than the basic on/off switch used in the digital approach? Digital devices show the way to fully-automatic unattended control: first, because each of the simple binary elements may be designed to have extremely high reliability, and second, because monitoring may be obtained by the incorporation of parity or error-checking codes.

As for performance: a prime advantage of digital systems is the facility with which they can handle control problems involving considerable computation. An example of this could be product quality control on-stream. The digital system can arrive at product quality by computation based on pertinent variables. An analogue system, however, soon runs into practical difficulties if required to perform extensive calculations, particularly when the nature of these calculations may change at short notice.

Several courses of action will be necessary before the digital system comes into its own. First and foremost, the interest and active participation of the control engineer must be aroused so that he can examine for himself how digital systems can be put to work with advantage in his own plant. A range of reliable digital transducers, of economic price, is required and, as an intermediate step, so are simple and reliable analogue-digital converters.

Standard digital 'bricks' will be necessary, and so will logical principles for their use in order that they may be produced cheaply and consistently in quantity and yet applied in tailor-made fashion to particular problems.

Furthermore, sampled data servomechanisms and high performance electric actuators should be developed to work in conjunction with digital systems where information usually flows on a sampled or statistical basis.

M. James.

Fig. 1 Short SC.1 VTOL research aircraft

Control at Farnborough

DESPITE THE FACT THAT THE AIRCRAFT industry is able to plead poverty with rather more justification than those other perennial pleaders, farmers and fishermen, this year's SBAC Show should be one of the most successful to date. There are 376 exhibitors, a record number, and the largest-ever number of overseas visitors is expected to attend. At the moment the industry's exports are running at about £175 million a year, so the potential buyer from overseas is very much the honoured guest.

The control and instrumentation engineer will find a great deal to interest him in the 195,000 ft² static exhibition. Many manufacturers of control and allied equipment tend to unveil their newer techniques and products at Farnborough, for reasons which are hard to decipher. It could be merely that control engineers like aeroplanes and, therefore, apply a possibly disproportionate amount of their energies to aeronautical problems. Furthermore, the Farnborough Show has the day-in-the-country sort of attraction that the better agricultural exhibitions have, an attraction that is often sadly lacking in the hot and dusty exhibition halls where control and instrumentation displays are normally held. Whatever the reason, the SBAC Show does attract the best in control engineering, and we hope to highlight the most interesting exhibits.

Navigational computation and control

Many firms with radio-radar backgrounds are showing airborne equipment which incorporates a data processing facility, most of it of an analogue nature.

Ferranti's **AIRPASS** (Airborne Interception Radar and Pilot's Attack System), which is housed as a single unit inside the centre body of the engine air-intake of the English Electric 'Lightning' (ex-P1) is shown for the first time (105-106) This is a pilot-operated search-and-track radar which incorporates a computer for working out the correct course for the final attack.

The Aviation Division of Elliott Brothers (218) are showing their **air data system** which provides centralized measurement, computation, correction and electrical transmission to servo-operated presentation units. They claim that it will enable improved instrument presentation and the opportunity to replace the conventional method of supplying aerodynamic information on an individual capsule instrument basis.

Elliott's are displaying a large model of the Vickers VC10 jet airliner, cut away to show their flight control system. This is a twin Bendix-Elliott **autopilot** installation either instrument being used in normal en-route flying. Each provides i.l.s. coupling with fully-automatic throttle control, v.o.r., clutched and pre-set heading control, and height, airspeed and Mach number locks. Dual yaw damper and dual automatic trim are incorporated. The system is completely transistorized with small plug-in computing and amplifier modules. A 'comparison monitor', comprising a set of sensors and computer elements, operates in parallel with the associated 'driving' autopilot to assess any differences between them and disengage the autopilot if tolerances are exceeded. Air data for heights, speed and Mach number locks

are derived from a sensor which employs servoed transducers with integrated computing elements. Potentiometers on the output shafts of the air data sensor control the gains of various autopilot and damper loops to ensure optimum auto-control. Electromechanical autopilot actuators are integrated into the VC10's powered controls. On 'manual', damper demands with restricted authority are added to pilot's demands; on 'autopilot' the power control position feedback is locked and replaced with electrical feedback. 'Auto-flare' and 'Autolanding' requirements are catered for.

Flight Refuelling have a model of the new long-range Meteor target U Mk. 16 on Stand 167. The long nose of this aircraft houses the new Elliott type B4 autopilot, which is yet another example of the coordinated concept in control.

Airborne computation is featured by Sperry Gyroscope (279) whose Industrial Division developed magnetic drums in collaboration with AT & E for automatic telephone networks. They are now developing storage drums for airborne computers. The Sperry **Radio Track Guide** is a simple airborne analogue computer which transforms data from ground radio aids using two coordinates, together with route data contained in a punched-card programme, into signals which indicate aircraft position as a tracking error and distance-to-go with respect to required track. The tracking signal output can be applied to a flight director or to an autopilot.

Several other companies incorporate airborne computers in navigational aids. Smiths Aviation Division (1-4) have their new, type 4, **Flight System,** and both

Marconi's Wireless Telegraph Co. and Canadian Marconi (12-16) show **Doppler Navigators.** The MWT Dopplers are available either as a sensor and indicator drive unit alone, giving ground speed and drift and distance flown, or as a sensor plus either of two computers to give much more information.

Canadian Marconi's Doppler, **DAGMAR** (drift and groundspeed measuring airborne radar), is exhibited in conjunction with their new CMA-601 navigation computer, a transistorized design weighing less than 25 lb. Basic navigational drift and heading data are obtained from the Doppler and the gyro compass, this providing the angular input to the computer, groundspeed from the Doppler tracker being the other input. Analogue working with groundspeed information delivered in the form of synchro data is also possible. Two systems of digital counters provide track and distance-to-go, one active and the other pre-programmed.

The **Decca Navigator,** with the type 930 flight log analogue computer is on Stand 59, and it is likely that **DIAN**—Decca Integrated Airborne Navigator—will also be shown. DIAN is an integrated Decca-Dectra-Doppler navigational system.

Gyroscopes

Ferranti's (105-106) hermetically-sealed **vertical reference gyro** (FS16), which provides pitch and roll signals for remote flight instruments, is $4\frac{1}{2}$ in. dia. by 9 in. long and incorporates 115/90V 3-line synchro and toroidal potentiometers on both pitch and roll axes. It has 360° roll freedom and ± 85° in pitch, and uses pitch bank erection. Two standby instruments will also be shown by Ferranti: a **standby artificial horizon** (FH7) which will operate from d.c., via a transistorized static control/invertor unit, if the aircraft's a.c. fails; a **standby gyro** system for a miniaturized artificial horizon and a directional indicator, which can be operated from a.c. or d.c. in aircraft having complex remote indicating systems.

The RAE-conceived **master reference gyro,** Mark I on S. G. Brown's Stand 78, consists of an azimuth gyro mounted on a gyro-stabilized platform. An aerobatically-free dynamic reference source, it electrically transmits roll, pitch and heading information to repeaters in the attitude and heading indicators. It also feeds the autopilot and the radar aerial stabilization system. The Brown MRG Mark 2 is nearly half the size and weight of the Mark 1: its stabilizing and azimuth gyros are mounted in tandem and the servo amplifiers are fully transistorized. The Bosch Arma **two-degree-of-freedom floating gyro** is now being produced by S. G. Brown under the name

'Arma Brown'. Conventional gimbal bearings are eliminated, the gyro being in a sealed sphere which is enclosed in a container filled with Fluorolube, so that the sphere has neutral buoyancy. The sphere is positioned by four ligaments. Random wander is 0·1°/h.

Honeywell Controls (Stand 220) are showing their GG99 low-cost **gas-driven displacement gyro,** a two-axis instrument, 4·5 in. long by 2·75 in. dia. which weighs under 4 lb. Primarily a one-shot gyro for establishing a roll reference in a spin-stabilized vehicle, and as a basic centre of yaw, elevation and roll, it can be re-activated by replacing the activating cartridge and recasing the gimbals. The '**Golden Gnat**' **rate gyro,** which measures 1 in. dia. by $2\frac{1}{2}$ long yet can withstand 100 g shock and 10 g vibration at 2000 c/s, is also shown.

Sperry Gyroscope (279) show their new range (CL11) of **Gyrosyn compasses** incorporating the 'Rotorace' bearing technique—counter rotations are applied to gyro sensitive axis bearings so averaging out frictional torques and giving a '10-fold increase in accuracy'. The

Fig. 2 Ferranti's AIRPASS being loaded into the nose of a Canberra for flight trials

free drift rate is 0·5°/h. A **twin-gyro stable platform** providing a fully-manoeuvrable attitude and heading reference is shown. This has two identical Rotorace gyros at right angles and is gimballed so that the platform establishes a heading reference and a vertical in the aircraft. The platform may be used with an amplifier, flux valve detector and compass controller to provide a heading reference with a free drift rate of 0·25°/h and a vertical reference with a drift of 2°/h. A new 4 lb **vertical gyro reference** is being developed for the major control and instrumentation systems on which Sperry is working, e.g. the Smiths-Sperry system for the Airco DH 121. This has a conventional movement and the free drift rate with the erection system cut off is less than 15°/h. It will provide synchro transmission for attitude information. Sperry also exhibit their standard range of gyro horizons.

Rate gyros and gyroscopic test equipment—a servoed gimbal universal tester

with automatic photoelectric read-out, a polar axis tester and a rate gyro calibration table—are among Graseby Instruments' exhibits (278), and MO Instrumentation (195) show precision bearings for gyros etc.

Accelerometers

Among their telemetry instruments, Hendrey Relays (221) have an **angular accelerometer,** type GW12, pattern B1, series 3, which has capacity ouput. This is available in ranges from ± 10 to ± 1000 rad/sec. Sperry (279) have a **single-axis accelerometer** developed originally for inertial systems. It is a force feedback instrument with a linearity better than 0·1% and a zero stability better than 6×10^{-4}g. Ranges of ± 10 g and ± 25 g are available from instruments by Ferranti (105-106). In these, the spring-mounted inertia forms a shorted turn of an electrical pickoff. As the mass moves the shorted turn upsets the flux symmetry in two secondary coils so producing an e.m.f. proportional to acceleration. Graseby Instruments (278) show voltage type accelerometers, accelerometer re-

Fig. 3 Experimental transistorized missile guidance equipment by GEC

corders, and three-axis accelerometer recording and telemetry units. The accelerometers of Electro Mechanisms Ltd (232) are in a rather different class. They include **variable inductance acceleration transducers** covering ± 3 to ± 90 g, **piezoelectric** (lead zirconate) types, and variable inductance push-pull types. An **accelerometer tester** is shown by Bryans Aeroquipment (204). This will test instruments weighing up to 14 lb and pro-

vides up to 20 g with a speed range from 10-250 rev/min.

Fuel control

Elliotts Aviation Division (218) have developed a Bendix **true mass fuel flow metering system** of the angular momentum type. Signals provided by a transmitter are computed for presenting the pilot with fuel consumed, fuel available and the time-of-flight remaining. Elliotts are working on systems whereby flowmeters which measure fuel consumed will also be used to measure fuel introduced into an aircraft, so enabling accurate flight planning.

An **electric throttle control** by Ultra Electric (262) is built round a positioning control which delivers a high torque output for jet and turbine engines. Temperature- or speed-controlled acceleration, speed governing and synchronization, and automatic airspeed control can be added.

Electric fuel control for the Gnome engine is shown by de Havilland Propellers (252). High stability magnetic amplifiers using toroidal transductors are used for control purposes and the system is powered from a transistor 24 V input supply. The system provides an automatic starting circuit, temperature controlled acceleration, a top temperature limiter, ground idling speed governing, and free turbine speed governing, the latter lending itself to multi-engine matching.

Plessey's Aircraft and Atomic Energy Group (60-62) is showing a fuel control unit for small gas turbines which will control turbine speed to within 1% and is capable of up to 70 gal/h fuel delivery. Plessey are showing various pumps including a 3-phase motor-driven centrifugal booster pump, and a governor pump type GP078 which supplies fluid at an output proportional to pump speed.

Negretti & Zambra (104) are showing their **fuel flowmeter** which is used on both the Comet IV and the Bristol Britannia. A direct reading cyclometer indicator is incorporated in the series 2 flowmeter, and this gives a full scale reading of 100,000 kg in 10 kg steps. The cyclometer is driven through reduction gearing by a low inertia integrating motor which is fed with a voltage proportional to flow rate. The voltage is derived from a precision rheostat through a pickup linked with the fuel flow rate indicator shaft.

Joseph Lucas (114) show a range of **engine controls** including simple flow control for the Dart, barometric pressure control (combined with idling by-pass, flow distributor, dump valve, non-return valve, and throttle valve) for the Orpheus, and range temperature control for the Avon and Conway. Among auxiliary controls are a pressure ratio limiter, air

fuel ratio control and jet pipe temperature control.

Among other firms showing fuel ancillaries of some control interest are Flight Refuelling (167), Saunders Valve (265), Zwicky (275) and Avery-Hardoll (241).

Pressurization, air conditioning and temperature

Normalair (75) are, of course, displaying a great deal of pressurization, air conditioning and oxygen equipment the central feature being **vapour cycle cooling**. Their exhibits include **passenger oxygen presentation** equipment, a liquid oxygen system, lightweight oxygen equipment, **electro-pneumatic temperature control**, and **pneumatic flow control** equipment.

Much equipment under this heading is on Teddington Aircraft Control's stand (35). **Cabin temperature control** systems using bridge-connected 'Ducstat' nickel wire temperature sensors, and a motorized selector consisting of a programme motor controlled by the first stage of the temperature control which drives monitoring potentiometers in the second stage of the servo, are shown. Teddington also exhibit **anti-icing, fuel tank pressurization** and **missile heating** equipment.

Hymatic Engineering (267) are showing a selection of **pneumatic equipment**, including a modular system of reducing valves: 5000 variants, inlet pressure from 100-4000 lb/in², outlet pressures from 1-150 lb/in², flows up to 30 standard ft³/min and temperatures up to 300°C. They have butterfly valves for boundary layer control and de-icing, a hot air reducing valve which incorporates a closed loop control system, various other reducing valves, anti-g valves and pilot-operated solenoid valves.

Apart from British Oxygen Aro's (192) display of crew emergency and passenger liquid oxygen systems, liquid nitrogen fire suppression systems, and

Fig. 4 Honeywell Control's 'Golden Gnat' rate gyroscope is 1 in. in diameter and 2¼ in. long

cooling systems, there is a family of **non-return valves**. These are available in both bobbin and flap types, have working pressures in the 0-6000 lb/in.², and may be compatible with corrosive fluids such as hydrogen peroxide.

Plessey (60-62) are showing a **temperature controller** for aircraft windscreens, which comprises a sensing element for detection and a contactor to control the heating circuit. It consists of a resistance measuring network, amplifier and relay: if the resistance of the sensing element rises to a preset level, the relay is de-energized and the contactor switched off; when the screen cools, the reverse process occurs.

Servos and ancillaries

S. G. Brown (78) are showing a range of **servomotors**, Admiralty pattern motors and step-by-step motors. Their 6·5 watt **transistorized servo-amplifier** operates at up to 90°C without a heat sink. Primarily developed for the Brown type 15B servomotor, it has an overall gain of 75 dB when operating from 250 ohm source impedance. Brown **continuous rotation low-torque precision potentiometers** are linearly accurate to within

Fig. 5 The 'Rotorace' (counter-rotation) directional gyro, which has very low gimbal friction, is incorporated in Sperry Gyroscope's Gyrosyn compasses

Fig. 6 Lucas fuel control unit for Avon and Conway gas turbines
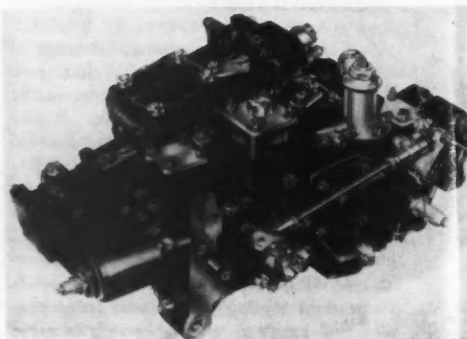
0.1% deviation, may have up to 35 fixed tappings in order to fall in with non-linear requirements, high load dissipation and low starting torques.

Ferranti's (105-106) **hydraulic jet valve** is for control purposes in servo systems; it converts a differential d.c. signal into differential oil pressure. The input signal is fed into control coils which vary the position of an oil-fed nozzle mounted on an armature. For zero input the nozzle is midway between two holes in a recovery block and it follows that there is zero resultant differential output signal. Any control signal will displace the nozzle to create a differential pressure between the holes. The differential pressure may operate a load either direct or via a servo valve. Two types are available (both having a range of differential input currents of $\pm$ 10 mA), one has a maximum differential output pressure of 700 lb/in^2 and the other a differential output of 1000 lb/in^2. A 150V d.c. supply is required for the polarizing coils.

Examples of Pullin-Kearfott **precision synchros,** sizes 11 and 18, are shown by R. B. Pullin (71). Pullin exhibits include: a size 10 two-phase squirrel cage induction servomotor with centre-tapped control phase for transistor control, and a size 10 motor generator with control phase wound for 26 V operation or centre-tapped for transistor operation; a transistor servo amplifier for sizes 10, 11 and 15 servomotors and motor generators; inter-service p.m. d.c. motors in 08, 11, 15, and 18 sizes; sizes 08 and 18 d.c. **tachometer generators;** wound field instrument motors; gears and gearboxes; **magnetic amplifiers** for sizes 15 and 18 servomotors. A dynamic display demonstrates **speed control** of governed motors over a widely fluctuating input voltage range.

Vactric (173) are also showing a comprehensive array of miniature servo components. This includes: size 07 to size 18 two-phase servomotors, synchronous motors, motor tachogenerators, fan motors and braked motors; p.m. and wound field d.c. motors from size 08 to 18; gearheads; and **breadboard components for servomechanisms.** They also have a **high speed rotary switch,** for telemetry systems, which enables up to 48 inputs to be sampled at up to 100 rev/sec.

Plessey (60-62) display the synchros and servos of Ketay Ltd and an **air motor servo** unit. Six Plessey **actuators** are on show: the Condor and Eagle a.c. linear, the Hawk and Kestrel a.c. rotary, the Cub Jaguar d.c. linear, and Squirrel d.c. rotary types.

Fairey Aviation's **electrically-signalled servo valves** are on Stand 206. Essentially these consist of a hydraulic servovalve of the flat face type, which is operated by a crank on the spindle of an electromechanical transducer or torquemotor.

The armature of the latter takes up a given angular position when a differential current is maintained in the field windings.

A range of synchros, a.c. **inductive pick-offs, motor-tachos** and a **precision potentiometer** are shown by Sperry (279), and they believe the potentiometer to be the most accurate for its size in the world. It is a helical potentiometer with a linearity better than 0.008%, 0.5 watt rating, and an effective angle of resistance of 18,000°, i.e. 50 revolutions. Sperry are also showing the **hydraulic pumps** and associated valves and controls, which they manufacture under licence from Vickers Inc. of Detroit.

Small motors and synchros are also featured by Smiths Aviation Division (1-4).

A **torque testing** machine by E.M.O. Instrumentation (195) is for measuring the starting and running torques of precision bearings and complete synchros. Electro-Hydraulics (162) show a selection of hydraulic components including selectors and brake control valves but the main feature of their stand is the Victor main undercarriage. DH Propellers (252) feature **hydraulic servo control** for their alternators.

Miscellaneous systems

H. M. Hobson (158) show a great variety of hydraulic and semi-hydraulic equipment including 'feel' **simulators** for the Britannia and Caravelle aircraft, **flap controls,** and an **autopilot actuator** for the Royal Navy. They manufacture the 'Microjet' **pressure ratio control** under licence from the Solar Aircraft Co. of America. This computes the ratio between two pressures and may be used either as a pressure ratio meter or as a sensor in a pressure ratio control system.

A **force-balance pressure ratio computer** is among Hendrey Relays' (221) aircraft instruments. Its output is an angular movement of the main spindle which is transmitted via a synchro to the pilot's receiver, where the rotation is 360° for the selected pressure ratio change.

Elliotts (218) are showing an aero turbine **engine analyser** which provides an air crew with oscilloscope presentations of vibration and temperature; the former indicates turbine balance at the bearings while the temperature is, in effect, the condition at the burners.

Ultra Electric's (262) **engine condition analyser** gives much the same data on engine vibration and temperature.

Honeywell Controls (220) have developed a **take-off monitor,** based on aircraft acceleration, which indicates any change in the aircraft's thrust and drag system. It also measures distance travelled, so providing information on the distance remaining to the refusal

point. Honeywell are also featuring their **data-handling** system, which measures, digitizes and logs signals from thermocouples, pressure transducers etc. They also exhibit an **automatic wave analyser** which plots frequency analyses of com-

Fig. 7 A new spherical-plug lox (liquid oxygen) valve with pneumatic actuator by Saunders Valve
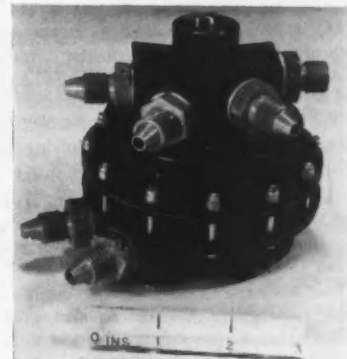
Fig. 8 This relay unit forms part of Normalair's pneumatic flow control. A normally-closed butterfly valve, operated pneumatically, is controlled by a venturi which senses flow and signals the relay unit to correct for air density changes

Fig. 9 Ferranti's hydraulic jet valve converts a differential d.c. signal into differential pressure
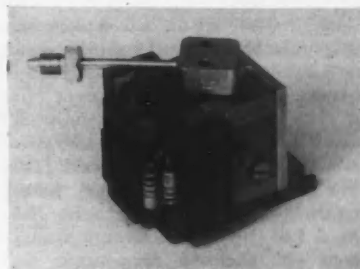
plex data signals in the range 3 to 2000 c/s.

A 12-channel **trace reading** equipment, type TRE12, exhibited by Southern Instruments (88), is capable of handling records 12-in wide and may have typewriter, tape perforator or punched card output.

Solartron (73) are demonstrating **radar simulators** and Short Brothers (26A) a quarter-scale model of a new **analogue computer**, said to be the most advanced of its kind in the world. Components of 0·01% accuracy are used.

Components for control and instrumentation

Most exhibitors are showing products which come under this general heading and it is difficult to decide when a component becomes a system.

Louis Newmark (189) show a **transistorized oscilloscope** which operates from 12 V d.c. but most of their exhibits are hardly components. They have a portable **pitot static test set** for calibrating flying instruments, autopilots etc; a **three-axis attitude indicator** which is a pictorial type aircraft instrument giving attitude and heading in all three axes; and a **response tester** for the functional analysis of a control system in situ.

Standard Telephones & Cables (145-148) show communications equipment mainly, but their **radio altimeter** for the 'Autoland' blind landing system (BLEU) is of control interest. This operates at 4000 Mc/s, covers 0-500 ft and 0-5000 ft ranges, and is capable of measuring an aircraft's height down to 2 ft.

Turning to components proper: BTH (272) show a great deal of electrical equipment including a **silicon power rectifier** (500A, 28V d.c. out from a 28V 3-phase wide-frequency a.c. input), motors and switchgear. W. H. Sanders (108) show **magnetic amplifiers** and encapsulated transductors and a **laboratory magnetic amplifier** designed as a control tool. Westinghouse (207) feature **semiconductor switching devices** including the 'Trinistor'. This is a three-terminal silicon device, basically a controllable diode, which in the forward direction may be triggered from a blocking condition to a conducting condition on the application of a small current to the third terminal.

BICC (165) exhibit a comprehensive range of cables. They also show stainless steel sheathed mineral-insulated **thermocouples**. Among other component firms of note are Venner Accumulators (84) who show their **silver-zinc and silver cadmium accumulators**, Ronald Trist (91) with their selection of **rubber materials** and seals, and of course, Belling & Lee (194) whose name is synonymous with **electronic components**.

Fig. 10 This engine condition analyser by Ultra Electric displays aero-engine temperature and vibration

Fig. 11 Louis Newmark's pitot static test set enables calibration of aircraft instruments and autopilots

Guided weapons

Nine missiles of one sort or another are in the Guided Weapons park.

Black Knight, a joint development of RAE and Saunders-Roe appears in two-stage configuration. A nose section of an experimental head which in a recent test, re-entered the earth's atmosphere from a height of more than 500 miles at over 8000 m/h can be seen.

The **Seaslug** ship-to-air missile is shown by Armstrong Whitworth in a ship-type launcher and missile power pack. This is a beam-rider and is to become the Royal Navy's standard shipborne anti-aircraft weapon. Guidance is by GEC and control by Sperry.

The Bristol-Ferranti **Bloodhound**, a semi-active homing surface-to-air weapon has already been delivered to the RAF and has been ordered by the Royal Swedish Air Force.

English Electric's **Thunderbird** also a semi-active homing surface-to-air weapon,

Fig. 12 W. H. Sander's laboratory magnetic amplifier is designed as a tool for the control systems engineer

is shown on its mobile launcher with tracking and illuminating radar and launch control post. The Thunderbird on view is operated by troops of a G.W. Regiment of the Royal Artillery.

Short Brothers & Harland are developing a surface-to-air guided weapon, the **Seacat**, for the Royal Navy. This is a close-range anti-aircraft weapon designed to replace the navy's 40 mm anti-aircraft guns. Short are investigating a variant of that weapon, the **Tigercat**, which is intended for use by land forces as a replacement for light artillery.

Both Vickers-Armstrongs and Pye are showing private venture **anti-tank missiles**. These are wire-guided weapons of small size and light weight.

Various weapons and ancilliaries are on show in the Exhibition building including the de Havilland Propellers **Firestreak**, an infra-red homing air-to-air weapon. The Ministry of Supply are showing a **Malkara** anti-tank missile.

Don't Miss

Bendix-Elliott VC10 autopilot *Elliott Bros.*	**Electrically signalled servo valves** *Fairey Aviation*
Doppler navigation *Marconi*	**Hydraulic servo control** *DH Propellers*
Two-degree-of-freedom floating gyro *S. G. Brown*	**'Feel' simulators** *H. M. Hobson*
'Golden Gnat' rate gyro *Honeywell Controls*	**Engine condition analyser** *Elliott Bros.*
'Rotorace' gyro compasses *Sperry*	**Take-off monitor** *Honeywell Controls*
Electric throttle control *Ultra Electric*	**New analogue computer** *Short Bros.*
Windscreen temperature controller *Plessey*	**Three-axis attitude indicator** *Louis Newmark*
Hydraulic jet valve *Ferranti*	**Data logger** *Blackburn Electronics*

Electric signalling to hydraulic valves replaces long mechanical control runs in an experimental aircraft

Electric link

for flying controls

by H. H. DIXON
Chief flight-test development engineer, Boulton Paul Aircraft Ltd.

AIRCRAFT USING HYDRAULICALLY OPERATED POWER CON-trols have now been in service for some time. Where flying aids such as automatic pilots have been intro-duced, these have usually been installed as in manually controlled aircraft, and they have been used to operate on the input run between the cockpit and the power control unit by means of servo systems. As this implies that two or more servo systems are being used when one is sufficient, there is obviously much to be gained by developing the main power control so that it will accept small electric signals from automatic pilots, fire control systems or navigational aids. This can be done in two ways; electrical signals can be fed into the units together with machanical signals from the pilots, or the pilot's signals can also be made electrical. It is with this latter philosophy that the experiment described below is concerned.

The aircraft used was originally a manually con-trolled machine but was subsequently fitted with power controls as a test-bed installation for the Vickers Valiant control system, and it was the system in this condition which was modified to incorporate electric signalling. The general layout for the three main flying control surfaces, aileron, elevator and rudder, is shown in Fig. 1, which is annotated to provide information on the location of the various parts of the manual and electric link system. The term *electric link* is used for the elec-trical signalling system that replaces the mechanical input linkage from the pilot to the power unit. It will

be seen from the electrical equipment located amid-ships that no attempt was made to install the lightest possible system, the main concern being to use existing equipment and to provide a simple, easily maintained and accessible installation.

Wires replace rods

Before conversion, the two sets of pilot's controls were commonly connected to a single set of control rods routed down the port side of the aircraft to the power unit located immediately aft of the rear cabin pressure bulkhead. This enabled both pilots to fly the aircraft with manually or power operated control surfaces, but to incorporate the electric link the common connexion of the two pilots' controls was removed. The result was that the port pilot could only fly the aircraft under manual control, and the starboard pilot under power control using electric signalling. It was possible for the crew to revert to manual control instantaneously under all flight conditions, reversion being automatic on fail-ure of the power system.

The power controls used in this installation consist essentially of an electric motor, a variable-delivery pump, a hydraulic ram, a servo control valve and a differential lever assembly. Movement of the pilot's control is transmitted to the input lever of the differen-tial gearbox, which in turn operates the servo valve. Subsequent movement of the servo valve causes the generator to supply fluid to one side or the other of the
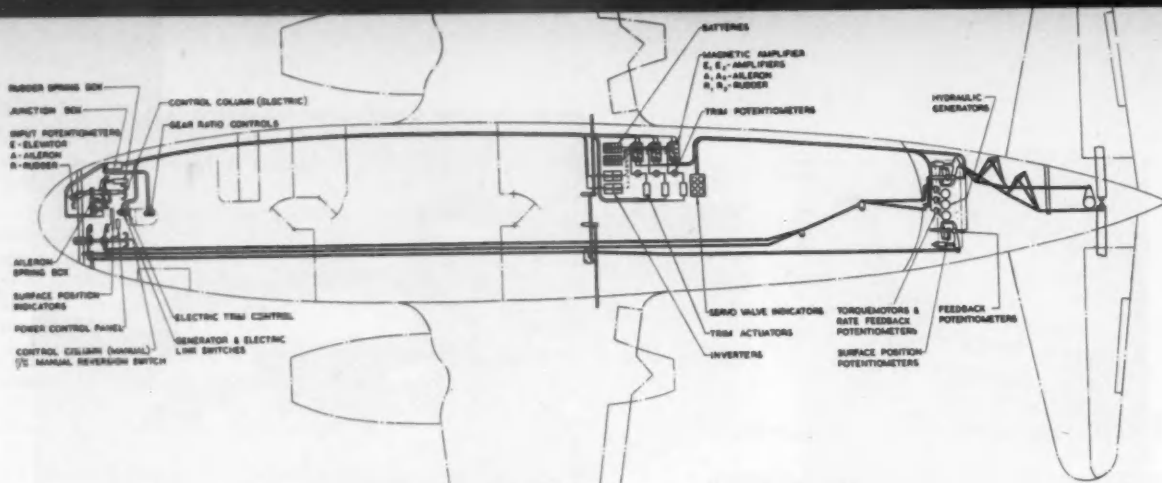
Fig. 1 General layout of the three main flying control surfaces

hydraulic ram that operates the control surfaces. Movement of the ram rod also actuates a feedback gear in the differential gearbox. This returns the servo valve to neutral, and so discontinues the hydraulic fluid supply from the generator to the ram. The control surface ceases to move when it reaches a position corresponding to the displacement of the cockpit control. The particular combination of hydraulic generator and servo valve does in fact constitute a primary and a secondary servo system, and it is this feature which ensures that there is virtually zero ' break-out ' load.

Fig. 2 shows simplified diagrams of the differential linkage used on this aircraft for controlling the servo valves when in power, and the method used for locking part of the system when operating the control surface manually. In Fig. 2a, when in power, the controls are held in the neutral position by the pilot, and the servo piston which controls the generator is in the zero-stroke condition. Fig. 2b shows the input lever displaced by the pilot and rotating the idler link about point A, point A being fixed while the ram is stationary. Since the differential lever is pivoted on the structure at B and pinned to the idler lever at C, the differential lever is displaced clockwise to move the servo piston. This allows pressure from the main pumps to be applied to the ram, which moves the output lever by an amount equivalent to the pilot's input. As shown in Fig. 2c, the linkage returns the differential lever, and therefore the servo piston, again to the zero-stroke condition. For manual use the differential lever is locked by the solenoid-operated plunger, the input signal being directly transmitted through the parallel linkage to the

output lever. The ram is made to operate freely by allowing the hydraulic fluid to flow from one side of the piston to the other through a bypass valve.

Introducing the link

In order to introduce the electric link, the connexion between the differential lever and the servo piston was removed so that the power control unit could be signalled electrically while the differential lever was permanently locked, thus establishing a permanent mechanical linkage between the port pilot's control system and the surface. The effort required to operate the piston is approximately one ounce, and a torque motor (i.e. Laws relay) can operate it, given suitable amplified electrical signals from the pilot. The feedback potentiometer, shown connected to the output lever, fulfils electrically the same function as the mechanical feedback linkage, and is further explained in the following general description of the link system.

In Fig. 3 the power unit as illustrated in Fig. 2d is shown complete with the control surface and pilot's input of the elevator system, and although the magnetic amplifier has been represented symbolically, all the principles of the installed system are retained. The basic principle of the electrical signalling system is that any change in current through the primary windings of the magnetic amplifier will cause a differential change in the secondary currents, which gives rise to a rotation of the torque motor. It will be seen that the input and position feedback potentiometers form a Wheatstone bridge, and any change in the position of the input will cause a current to flow through the primary winding,

Fig. 2 Power-unit control system a Control neutral b Generator servo-valve operated by pilot's demand c Surface displaced, servo-valve returned to neutral position d Power unit and differential linkage modified to incorporate electric signalling
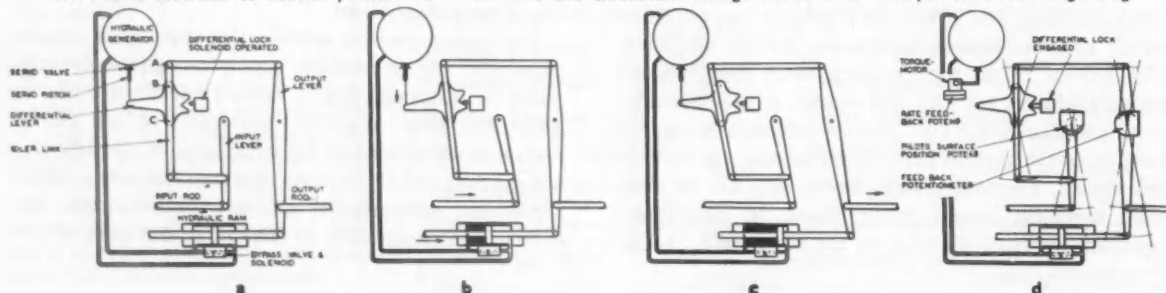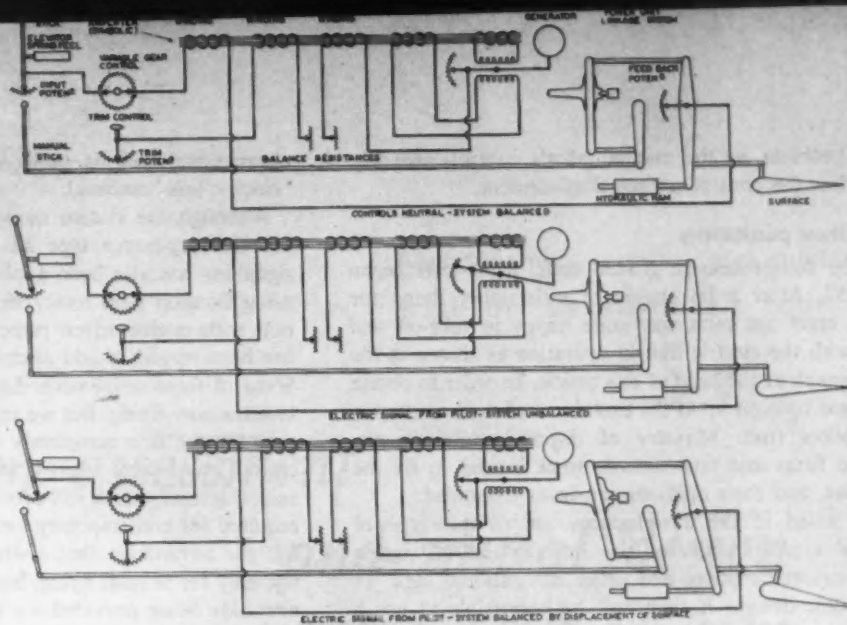
Fig. 3 Electric-link control system with manual reversion

and so move the system until the feedback potentiometer has taken up a new position which reduces the primary current to zero. The aircraft can be trimmed for varying flight conditions by displacement of the trim potentiometer, which causes a current to flow through the trim winding. The surface then moves relatively to the pilot's controls until the current in the control winding balances that in the trim winding. The purpose of the rate-feedback potentiometer is to control the sensitivity of the torque motor, insomuch as movement of the potentiometer in either direction from the neutral position causes a current to flow through the rate winding and tends to re-centralize the torque motor. This in effect stiffens the torque-motor shaft, and produces a more responsive control system.

The diagram shows the functioning of the system in response to the pilot's demand. It will be seen that, as previously shown in Fig. 2d, the port pilot's controls are permanently connected to the control surfaces so that they also follow the demands made electrically by the pilot on the starboard side. In the case of failure of the electrical system, the port-side pilot can press a master switch to open bypass valves across the hydraulic rams, thereby rendering the electrical system innocuous and giving him full control of the aircraft. It is of interest to note that the electrical system incorporates variable gearing between the pilot's controls and the surfaces. This feature is easy to incorporate into an electrical system. In the present case the gearing can be varied from 1:1 to 4:1 by adjusting potentiometers to provide a reduced signal to the magnetic amplifier for a given input, and consequently a reduced surface movement, thus enabling the pilot to select the best control response for different flight conditions. The normal manual pilot's control loading, or 'feel,' occasioned by the air loads on the control surfaces, is replaced in the electric-link control system by a simple spring feel system, as typified in the diagram for the elevator control.

Doubling for safety

The electrical components are duplicated throughout to give a two-channel system which ensures that failure of the link can only arise if an electrical defect occurs in both channels simultaneously. For the same reason the hydraulic supply to each jack is duplicated by controlling the servo valves on one bank of two different generators for each surface. The input, feedback, rate feedback and trim potentiometers are supplied with 24 V d.c., and the magnetic amplifiers with 115 V a.c., from two separate sources which are unconnected with any other aircraft system. As previously stated, complete failure of the hydraulic power supply is followed by automatic return to manual control, but a failure of only one generator would still provide a full-stroke, half-rate system on the two affected surfaces, with a visual indication to the pilot of the surfaces concerned. A more comprehensive instrumentation system for indicating the malfunctioning of the electric link is provided, and this displays to the crew the continuous functioning of the servo valves, the movement of these being transmitted by electrical signals from a.c. pick-offs. For correct functioning the two servo valves for each surface move in the same direction and in phase. With the type of indicator used, i.e. milliammeters, it is possible quickly to discern any adverse changes, allowing the crew to take remedial action by switching off one or both channels.

One other system which is an essential part of this installation is the indication to the pilots of surface and trim position, since, before going from manual into power, the electric signalling system must have the correct signals to agree with the actual position of the control surface. This is necessary because, until switched on, the pilot's electric controls are divorced from the surface movement, and it would be possible to get sudden and violent changes in surface displacement if the electric signal were not correct at the point of change-over. From power to manual control there is no

such problem, as the manual pilot's controls (see Fig. 3) follow the control-surface displacement.

Tests show possibilities

After comprehensive ground tests, flight tests began in 1957. After a few hours of satisfactory flying the firm's chief test pilot was quite happy to take-off and land with the electric link in operation as shown in the photograph at the head of this article. In order to obtain unbiased opinion upon the usefulness of such a scheme, test pilots from Ministry of Supply establishments, private firms and civil airlines were invited to fly the machine, and their opinions are being examined.

As stated in the introduction, use of this type of control system facilitates the introduction of signals from automatic pilots and other navigational aids. In supersonic designs it may well be impossible to use a conventional rod or cable input system, making the 'electric link' essential.

Although the system shown here relies on the variable-delivery-pump type of power control, electrical signalling has also been applied successfully to systems using Boulton Paul rotary valves and jacks in conjunction with engine-driven pumps. With either system, it can be arranged to add electrical to mechanical signals. Some of these refinements have already been built into systems now flying, but we may still have to wait some time for the first completely electrically controlled aircraft. Considerable effort is still being made to develop such a system, which will provide all the safeguards now required for contemporary aircraft, and to utilize to the full the advantages that electrical control can provide, not only for normal flying, but in the integration of the new aids being provided for navigation and approach.

The all-electric aircraft obviously will not appeal to everybody, but Dixon's article indicates that some steps in that direction will be hard to resist. In his comments below, Professor G. A. Whitfield, B.Sc., Head of the Department of Aircraft Electrical Engineering at the College of Aeronautics, Cranfield, suggests that the first steps should not be too bold.

I FOUND THE ARTICLE BY MR. DIXON ON 'AN ELECTRIC link for Flying Control' most interesting, particularly because it deals with an actual experiment in a field being considered on theoretical grounds by many aircraft designers. On first consideration it would seem to be most inefficient to transmit the demands made by the pilot for control surface deflexion by means of rods or cables passing down the whole length of the aircraft, when all that is done at the far end is to move small hydraulic valves. This is particularly so in modern aircraft in which the electric signal from an autopilot or autostabilizer must operate the same or similar valves. An additional factor favouring electric signalling is that in the mechanical system there can be no tight servo loop, so balance weights have to be mounted on the control surfaces. One estimate* suggests that use of an all-electric system would save 1000 lb weight, enabling the aircraft to carry four more passengers. The reason that 'all-electric' systems have not yet been adopted is that designers and operators are not confident as to reliability, and they have considerable justification in this.

There is, in civil aviation, one bad crash for about 250,000 hours' flying time. A minimum requirement for the controls might be that they should cause less than one such accident in every 4,000,000 hours' flight. There being three control systems, one each for the rudders, elevators and ailerons, each of these must cause less than one accident in every 10,000,000 hours of use. There is no possibility of designing a single communication channel with this reliability.

Is doubling enough ?

Mr. Dixon suggests full duplication — two channels per system. Suppose each half fails once every 10,000 hours. When such a failure occurs the aircraft concerned will be vulnerable to a single failure for the remainder of the flight, say three hours. In three cases in 10,000 such a failure will occur, giving three acci-

*Power Controls for Aircraft by H. C. F. Joy—Journal of the R.Ae.S. Jan. 1957

dents per 100,000,000 hours, which is little better than is suggested above as a minimum requirement. The need is, therefore, for control channels which fail not much more frequently than once every 10,000 hours. Of course, the equipment can be serviced thoroughly and components replaced every 1000 hours of flight, say every three months, and be 'maintained' more frequently, which eases the design problem somewhat.

Even this understates the real requirement. Almost any failure of both channels of the electric link would be fatal. Mr. Dixon suggests that the crew should minitor the links and cut out faulty ones. Now the least dangerous failure is that one path should become inoperative, thus halving the loop gain. This by itself might well cause an accident during take-off or landing before the pilot could readjust himself. An obvious solution is to fit a quick-acting device to double the gain of the remaining path, but this would entail an increase in the size of each hydraulic actuator. It also presupposes that the device could detect which channel is faulty, and this can only be done by triplicating and taking a majority vote.

Another possibility is that one channel should fail in such a way as to demand full control and this would give half-full control. Under many flight conditions this would be applied before the crew could act and would break the aircraft. Again triplication would be necessary.

Introduction of electric links will, therefore, depend on the very careful detailed design for 'fail safe,' and also the production of channels which can be guaranteed to fail not more than about once every 10,000 hours, which is equivalent to full-time operation for about one year. In the later stages of development it would therefore be necessary to test some dozens of equipments, under different environmental conditions, for at least three months after production models were available. If a failure occurred in any of these, modifications would have to be introduced and a further three months would be spent in retesting.
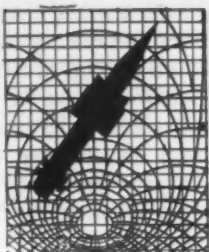
Aerodynamics, control and guidance
must be designed all together

System assessment
and initial design

by **PEGGY L. HODGES,** M.A., A.F.R.AE.S.

Group leader of G.W. Systems Analysis Group,
GEC Applied Electronics Laboratories, Stanmore, England

FOR A NEW GUIDED MISSILE PROJECT IT IS ESSENTIAL that the basic theoretical design is carried out in considerable detail and the performance of the resulting system assessed as far as possible before any component parts are made. The performance of the complex missile system involves problems of aerodynamics, control and guidance, the solutions of which are interdependent. Detailed assessment must therefore include paper studies followed by more complex calculations using both digital and analogue computers.

This article endeavours to give some idea of the philosophy behind these studies, discussing briefly some of the individual problems encountered, together with the many possible answers, and giving a general indication of the method of approach to the best solution. Mention is made of the use of simulation in association with the missile trials carried out after the initial design has been engineered and prototypes produced.

To illustrate the techniques involved, one particular problem, namely dish-missile coupling in homing systems has been taken, and the methods by which its destabilizing effects are investigated are discussed in some detail.

System approach

The theoretical approach to the design of a complete system for a guided missile may be illustrated by means of a flow diagram as shown in Fig. 1. The first essential is a knowledge of the operational requirements for the whole system—these may be divided into two parts. First, the type of system must be known, i.e. whether the missile is to be launched from land, sea or air, and whether the target the missile is attacking is land, ship or aircraft. Secondly, basic parameters of the target must be established, such as size, velocity, altitude and manœuvre, together with the target range at which the missile will be launched. For the next step, the system is divided into two: the missile system is treated separately from the associated equipment, which is mounted either at the launcher or some other convenient place. The form of the latter, which will not be considered in detail, depends greatly on the type of guidance used—hence the feedback shown in Fig. 1.

After the basic design of the missile system as required by the tactical situation has been established, the necessary missile performance is obtained by the design of the aerodynamics, propulsion, control or autopilot, guidance, fuze and warhead. The last two will not be discussed any further in this article—the major effect the warhead design has on the overall system is in determining how near to the target the guidance equipment must take the missile. The size of the warhead also affects the overall weight of the payload carried by the missile—the payload includes everything but the motor and the missile structure.

Major design decisions

The above parts of the missile design cannot be treated separately and there follows next a brief discussion of some of the major decisions to be taken before the missile parameters can be determined, with emphasis on the close cooperation required between the designers of each part.

The choice of parameters in the design of the aerodynamics and propulsion of the missile is determined by the missile system requirements such as range, altitude, manœuvre and weight. The aerodynamic design is also affected by the choice of guidance and control, determining, for example, whether there are two or four wings and also whether the control is obtained by moving fins, by moving the main wings, or by jet controls.

The autopilot improves the missile's performance

The main purpose of the missile autopilot is to alter the response to a fin demand from one which is sluggish and lightly damped to one which is faster and more heavily damped. The autopilot also serves to make the
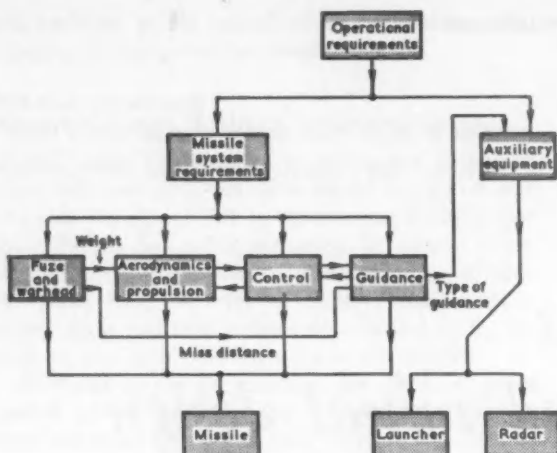
Fig. 1 Flow diagram of a guided missile system, showing the approach to system design

performance of the controlled missile, i.e. the missile with autopilot, less variable with velocity and altitude—this point has already been discussed in a previous article in this series (*1*). The parameters of the autopilot are therefore very dependent on the missile aerodynamic characteristics once the type of control to be used, for example a rate gyro, has been established. They are also affected by the choice of guidance, since this has a considerable bearing on the desirable controlled missile performance.

Choosing the kind of guidance

No attempt will be made in this article to discuss all the possible guidance systems together with their advantages and disadvantages. Some of the more widely used have already been listed in the introductory article to this series, and give an idea of the choice available. Most known systems fall into one of three categories: *beam-rider, command link* or *homer*.

Beam-riding and command link systems

The beam-rider is guided to fly along a radar beam towards the target. The powerful radar beam, usually from a ground- or ship-based transmitter, may be always directed towards the target (*line-of-sight beam-riding*), or may be programmed so as to cause the missile to fly along a specific trajectory (*command beam-riding*). Beam-riding has the advantage of simplicity, yielding linear equations when dealing with the theory of the system. A line-of-sight beam-riding system requires less ground equipment than a command system, as the latter must include some form of computer to calculate the required commands. However, a beam-riding system can engage only one target at a time and the accuracy of the guidance decreases with radar-target range. Moreover a line-of-sight beam-riding missile trajectory is not the optimum one from the point of view of missile aerodynamic range. Line of sight beam-riding has been discussed in some detail in a previous ⁻le in this series (*2*).

Command link systems, as the name implies, function by virtue of a link, frequently radio, between operator and missile, and thus the missile is controlled to follow the desired course; command beam-riding can be included in this category. Command systems have the advantage that a powerful transmitter may be used and there is considerably less missile-borne equipment required than with other systems. See the first article of this series, on visual command guidance (*3*).

Homing systems

The third category—guidance by homing—is most generally used for short range missiles, or the final stage of longer range missiles, since the useful range of a homing system is determined by the size of the homing eye in the nose of the missile. Homing systems have the major advantage that the accuracy is dependent on missile-target range and therefore increases as the missile nears the target.

Homing systems can be subdivided into three groups: active and semi-active systems operate with radar, completely missile-borne in active systems. In semi-active systems only the receiver is carried by the missile. Passive homing, the third group of systems, relies on the target itself to provide the information source, the missile carrying a receiver; a missile with an infra-red homing head operating on the thermal output of the target engine is an example of this group. A missile using active homing carries a much smaller transmitter than is used with a semi-active homer or a beam-rider, and is therefore more susceptible to enemy jamming. In an active homing system, the missile carries the transmitter used for illuminating a target, and once it has been launched it is, therefore, independent of any other equipment. In semi-active homing, the illuminating transmitter is usually carried by the launcher. This system can considerably restrict the tactics of the launcher after the missile has been released, particularly if ship- or air-borne, since the radar must continue to illuminate the target throughout the missile flight; however it does call for simplified missile-borne equipment.

Clearly the type of guidance system chosen greatly affects the associated equipment required in the whole system. For example, both beam-riding and semi-active missiles need a large target-illuminating radar, whereas an active or passive homing system does not require any additional equipment once the missile has been launched on the correct course.

Design technique

To give some indication of the technique of solving these problems, it is convenient to divide the aerodynamicists, engineers and mathematicians working on the system into two groups. On the one hand there are the theoreticians working with pen and paper and helped by both digital and analogue computers to produce the basic design parameters. On the other there are the component engineers who try to design and make equipment which has the required theoretical preformance.

Obviously no rigid boundary exists between the two groups; the component engineers frequently supply the theoreticians with parameters which will be realizable in practice. The general design approach can be illustrated by reference to Fig. 2.

Calculation and simulation

The initial theoretical design, such as selection of guidance, is undertaken on quite crude assumptions. This enables fairly simple analysis to be carried out, resulting in rough values of the basic system parameters. These calculations are followed by simulation of the problem using either a digital or an analogue computer. This simulation ignores a number of the early simplifying assumptions and may include some non-linearities of the system. The result of the simulation is a first set of values of parameters, which will give an optimum performance for the conditions considered so far.

A complex missile system has a number of factors which ideally should be negligible, but which in practice decrease the stability of the system. These include cross-coupling, that is interaction between the performance in the separate control planes, and this can lead to phasing error in beam-riding systems (2). Another factor is dish-missile coupling, which can be very troublesome in homing systems. This effect arises from coupling of the missile motion into the performance of a space-stabilized auto-follow dish system, and is discussed in more detail later.

The next stage in the design is the simulation of the system including the destabilizing factors, and results of this may demand a change in the first selected values of the parameters.

Another consideration at this stage is the effect of

Fig. 3 Block diagram to illustrate destabilizing effects due to aberration in a homing system

noise on the system. This may be caused by the missile electronics, but external noise is usually more important. Noise can, for example, be due to *jitter* on the radar beam in a beam-rider or to *target glint*, i.e. random motion of the point of reflexion of the target, in a homing system. In both types of system, noise can also arise from reflexion of part of the transmitted power from the earth's surface; this is generally referred to as *clutter*. The simulation may be extended to include more complex target manœuvres than were considered initially.

Optimized parameters

The outcome of the above analysis and simulation is a set of optimized parameters which will give the most satisfactory missile system performance, taking account of all the more obvious factors which affect the performance. These optimized parameters are then handed to the component engineers who try to design a realizable system with the desired performance. One often finds, in an engineered system, that the theoretically optimized parameters are not mutually compatible; then fresh suggested values are passed back to the simulator operator so that the effect of these on the performance of the optimized system may be discovered.

Before the engineered equipment goes into production it is also essential to discover the effect on system performance of those component tolerances which will be experienced in the manufactured design.

Manufacture and trials

The missile and all its component parts are next manufactured, and after tests in the laboratory and simplified firings, a number of missiles are fired at trial targets. The values of numerous variables within the system are monitored and telemetry records obtained during the missile flight trial. The missile trajectory is also followed by instruments such as cameras and kine-theodolites. All these resulting records are analysed and thus the performance of the missile and its component parts during the flight is fairly well known.

Simulation again

It is at this stage that the simulator is again brought in. If an analogue computer is arranged so that it solves

Fig. 2. The sequence of work in designing a guided missile system. The method by which each step is made is shown in the shaded boxes

the missile performance with the inclusion of as many as possible of the known factors such as non-linearities, cross-coupling effects, and noise, it is then possible to simulate a missile trial, and monitor, from the simulator, records which are similar to those obtained from the actual trial telemetry. The simulator can then be used in three ways:

1. An estimate can be obtained, before any specific trial, of the likely missile performance and the amount of variation there may be in the monitored variables.

2. If something unexpected occurs in a given trial, the trial conditions may be set up on the simulator, and if the phenomenon is repeated on the simulator it is then possible to investigate the cause. If it does not recur in the simulated trial, a number of modifications can be made to the simulated problem and hence an estimate obtained of a possible fault in the trial which could have given rise to the unexpected effect.

3. It is not always possible to carry out trials with targets the performance of which is similar to that of the ultimate missile target. In this case a simulator can be used to extend the trials, as the effect of the theoretical target performance can be set on the machine.

System design example : dish-missile coupling

One of the most troublesome destabilizing effects which must be taken into account in designing a successful homing system is that due to coupling of the missile motion into the performance of the auto-follow loop. A gyro-stabilized dish system forms part of the auto-follow loop which enables the radar aerial to be kept continuously pointing towards the target. Ideally this system is stabilized with respect to space axes and should be independent of the missile motion. However, a number of factors in a practical system cause the behaviour of the stabilization system to be affected by the missile. Two of these are mentioned in the article on homing systems (*1*). One is refraction of the sight line by the radome which forms the nose of a homing missile, the amount of refraction depending on the angle of look of the dish. Thus this refraction is a func-

tion not only of the direction of the missile-target sight line in space but also of the missile heading in space. The second is the finite stiffness of the servo, and this an example of the type of coupling which depends on the particular tracking system used. Dish-missile coupling can also be brought about by imperfections, such as friction at the bearings or backlash, in the actual operation of the mechanical system.

Improving stabilization

Once the mechanical design of the stabilization system has been decided, it is possible to obtain some estimate from the mechanical engineers of the magnitude of the parameters which determine the amount of coupling. Simulated missile flights carried out with the inclusion of the particular form of dish-missile coupling under consideration give estimates first of the resultant stability of the system and secondly of the effect of the coupling on the miss distance obtained. Frequently first estimates of the parameters obtained from the mechanical engineers lead to an unsatisfactory overall missile performance, and the designers are called in to look again at the stabilization system and improve it in such a way as to reduce the amount of coupling. For example, the destabilizing effect due to radome aberration depends very much on the shape of the radome which is being used with the missile. Simulated flights can lead to limits being placed on the amount of aberration which is consistent with satisfactory missile performance. These limits in turn restrict the shape of the radome, in particular the ratio of length and diameter. This information on radome shape must then be passed back to the aerodynamicists since it can affect the aerodynamic performance of the missile to a marked degree.

The effects of radome aberration

To illustrate the way in which these destablizing effects are investigated, the problem of radome aberration will be discussed in rather more detail, repeating for completeness some of the points already mentioned in this series by Sendles (*1*). A block diagram of the system is shown in Fig. 3. The missile radome refracts the true direction of the missile-target sight line ψ_S such that the target appears to lie in a direction ψ_{SA}, where

$$\psi_{SA} = \psi_S + \varepsilon$$

The amount of refraction, or *aberration* as it is more generally called, depends on the particular part of radome at which the radar dish is pointing; thus the error ε is a function of the angle of look, i.e. the angle between the sight line direction and the missile direction ψ_M, all angles being referred to a datum in space.

Thus $\qquad \psi_{SA} = \psi_S + \mathrm{f}(\psi_S - \psi_M)$

A missile homing on proportional navigation derives the guidance signals, which are used to move the control fins, from the measured rate of turn of sight line.

Fig. 4 Response of missile acceleration to a step change of sight line for various values of aberration *A*

A_{NC}

$\frac{1}{2} A_{NC}$

$\frac{1}{2} A_{PC}$

A_{PC}
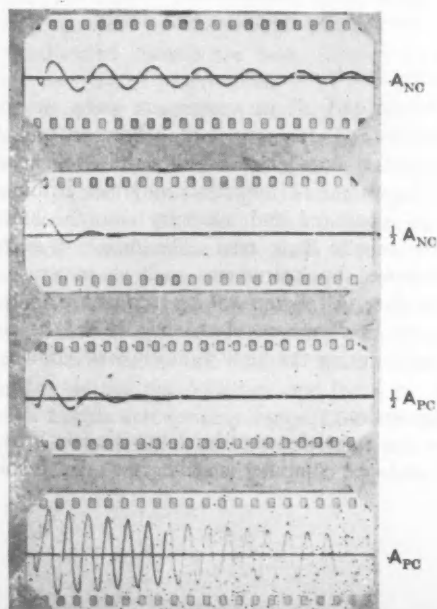
If ψ_{FD} is the desired flight path direction, the navigation law becomes

$$p \, \psi_{FD} = k \, p \, \psi_s$$

where $p = \dfrac{d}{dt}$, and k is a constant

or if aberration is present

$$p \, \psi_{FD} = k \, p \, \psi_{sA}$$

Therefore $\quad p \, \psi_{FD} = k[p \, \psi_s + pf(\psi_s - \psi_M)]$

and it is the rate of change of the aberration error which affects the missile guidance. In order to carry out the preliminary paper analysis, the curve of aberration error against angle of look is assumed to be a straight line of slope A, i.e. *linear radome aberration.*

The navigation law may now be written as

$$p \, \psi_{FD} = k[p \, \psi_s + p \, A \, (\psi_s - \psi_M)]$$

or $\qquad p \, \psi_{FD} = k(1 + A)p \, \psi_s - k \, A \, p \, \psi_M$

The radome aberration can thus be seen to have a double effect, first it has modified the navigation constant k and secondly it has introduced a term dependent on the missile motion, the dish-missile coupling effect.

When does the system become unstable ?

If the missile system is assumed to be such that the achieved rate of turn of flight path $p \, \psi_F$ is related to the demand by a second-order function

$$p \, \psi_F = \frac{p \, \psi_{FD} \, \omega^2}{p^2 + 2\zeta\omega p + \omega^2}$$

and the missile heading and flight direction are related to the incidence lag T_B by

$$\psi_M = \psi_F(1 + T_B p)$$

the transfer function relating achieved rate of turn of flight path to rate of turn of sight line becomes

$$\frac{p \, \psi_F}{p \, \psi_s} = \frac{k \, \omega^2(1 + A)}{p^2 + (2\zeta\omega + kAT_B\omega^2)p + \omega^2(1 + Ak)}$$

It can be seen from the above that the system will become unstable if

$$2\zeta\omega + kAT_B\omega^2 \leqslant 0$$

i.e. if $\qquad A \leqslant -\dfrac{2\zeta\omega}{kT_B\omega^2}$

Thus if the missile parameters are known, this critical value of negative aberration slope A_{NC} can be calculated. Alternatively the missile parameters are determined by a given amount of aberration.

In practice the rate of turn of sight line is measured by a radar and dish servo system, and the measured rate therefore lags on the actual rate. This lag may be approximated to by another second order function with parameters ω_D and ζ_D such that

$$(p \, \psi_s)_M = p \, \psi_s \frac{\omega_D{}^2}{p^2 + 2\zeta_D\omega_D p + \omega_D{}^2}$$

If the effect of this dish servo is now included in the

Fig. 5 An analogue computer used in guided missile simulation

analysis, it can be shown that the system will become unstable, not only for a critical value of negative slope A_{NC} but also for a certain value of positive slope A_{PC}, the response having two modes of oscillation the damping of which varies in opposite directions as the value of A is changed.

Calculating permissible aberration

The next step is to set up the system on a simulator, replacing the simple missile transfer function by a more exact representation of missile and autopilot. The way in which the missile response varies with change in the value of aberration slope may be seen in Fig. 4 which shows responses of achieved missile acceleration to a step change in missile-to-target sight line direction for various values of A. The maximum values of $\pm A$ taken are slightly less than critical.

The simulator can now be used to obtain estimates of the miss distance achieved for various amounts of aberration. This is done by closing the loop between achieved acceleration and rate of turn of sight line with a kinematics computer solving the geometry of the system. From these results the maximum amount of linear aberration which will give a satisfactory missile performance can be estimated.

In practice the curve of aberration error against angle of look is by no means linear and the above simulation is repeated using actual curves, which have been taken from measured radomes, in place of the linear relationship. It is frequently found from this latter block of simulation that the performance of the missile with the practical radome necessitates changes in the dish servo parameters which have previously been selected. As mentioned earlier in this article, the simulation is also repeated with the addition of noise, in particular that due to target glint, the random motion of the point of reflexion of the target. From the results of this simulation the value of miss distance which can be achieved in practice can be estimated.

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1. Sendles, J. L.: ' Semi-Active Homing,' *Control,* 1959, 2 (June), p 71
2. Joiner, H. R.: ' Radar Beam-Riding,' *Control,* 1959, 2 (August), p 75
3. Allen, D. W.: ' Visual Command Guidance,' *Control,* 1959, 2 (March), p 57

PART 1

These standard devices are being turned to a new use in the steel industry. Their employment in rolling mills is described here as a pointer to other possible applications

Uniselectors

enter automatic programme control

by **H. LAW**, B.SC., A.M.I.MECH.E., A.M.I.E.E.
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IN MANY INDUSTRIAL INSTALLATIONS TODAY THERE IS AN increasing demand for greater production and increased quality of product. Performance on manual control is now approaching the limit, and much effort is at present being expended in developing suitable automatic programming and sequencing equipment.

In ferrous and non-ferrous rolling mills, for example, automatic programming equipment will provide, at the correct time and in the correct sequence, reference signals for the automatic position control of screws, edgers, manipulators etc., or for the automatic speed control of the main drive, inlet and outlet tables etc. In hot tandem mills, references for the speed, screw setting and tension of each stand are required, and cold mills require in addition automatic gauge-control reference signals. The magnitudes of the signals themselves are determined either as preset stored values or from computation by the equipment itself. Thus installations will vary considerably depending upon the type of mill being controlled, but, broadly speaking, programming controls can be divided into groups according to whether they are based on (a) uniselectors and relays, (b) plugboards or setting potentiometers, (c) punched cards or tape, or (d) analogue or digital computers. These groups are briefly described below.

Uniselectors and relays

Equipment based on uniselectors may be employed where the required schedule or programme of settings for a particular product can be determined largely before production commences. A limited number of programmes can be stored conveniently (about a hundred) and access is very rapid. If there is any similarity between the various programmes it is possible, by arranging for programme changes during rolling, to increase this capacity greatly without enlarging the equipment.

This type of programmer would be suitable for the class of hot or cold reversing mill or tandem mill (initial setting), where the total number of programmes handled is limited but where the change of programme is frequent. Plugboards can be used for experimental programmes, or those which are seldom required. Also in this category are draft controllers of various types.

Plugboards or setting potentiometers

As a simplified version of the equipment described above it is possible to use plugboards alone in conjunction with sequencing relays. As an alternative to plugboards, position- and speed-setting potentiometers can be used, and early automatic programming equipments were based either on these, or on plugboards. However, this type of equipment has the major disadvantage that the setting of each new programme is laborious.

Punched cards or punched tape

This equipment would have applications similar to those of the uniselector-type programmer, but would be used where the number of stored programmes required is very large. Punched card or tape programmes could therefore be used for a mill having a large range of products, but where the next programme required is known for a reasonable period beforehand. That is, the access time for this equipment is much longer than for the uniselector type of equipment. As before, plugboards can be included for experimental or rarely used programmes.

Analogue or digital computers

This type of equipment may be used where it is necessary to make settings which are dependent upon the results of action by other controls. Computers could

suitably be used for production control, and for obtaining on a probability basis the maximum utility for a product, e.g. cut-length control on a sawbench. They could also be used in conjunction with punched-card or uniselector equipment to control, for example, screwdown, speed, and tension continuously on each stand of a hot or cold tandem mill; or to make corrections dependent upon temperature and load after each pass on a hot or cold reversing mill.

UNISELECTORS CHOSEN FOR STEEL MILLS

The basic uniselector scheme was devised for automatic screwdowns by the British Iron and Steel Research Association, and from this complete automatic programming equipment has been developed in the form of standard units which can be assembled as required for any particular application.

A uniselector is essentially a multi-way multi-level selector switch. There are two main types employed in this automatic programming equipment: ratchet uniselectors having eight levels, each of 25 contacts, and motorized uniselectors having sixteen levels, each of 51 contacts. The former type is actuated by a solenoid-operated ratchet mechanism that moves the wipers forward one position each time the solenoid is pulsed. The latter type is driven by a small motor, and the associated circuits ensure that, when control signals are applied to the motor, the wipers stop or start almost instantaneously. Thus if one of the sixteen levels is used to control the position of the uniselector, any required position can be obtained by energizing, or 'marking,' the appropriate contact on this level by means of, for example, a multi-way single-pole switch. This prepares a control circuit through the associated wiper, and the uniselector will then move until the control circuit is closed when this wiper reaches the selected contact. The motor then stops before the wiper leaves this contact. By using two levels and two selector switches in series it is possible, in a similar manner, to make the marked position dependent upon the combination of the settings of the two switches. Thus if two seven-way switches were used, 49 of the 50 possible ways could be selected.

Taking this a stage further, the uniselector setting can be controlled by a number of selector switches in series, each being associated with a separate level (see Fig. 1a).

With this type of programmer there are four main stages in the operation of the equipment (see Fig. 1). These are programme selection, programme storage, pass selection, and the digital output reference signal. The four stages are discussed in more detail below.

Programme selection

Any particular programme, or schedule of settings for screwdown, manipulator, speed, etc., can be fixed if full information regarding the dimensions and physical properties of the piece to be rolled is known. Thus the input dimensions or weight of the piece, the tem-

perature, the type of material, and the required finished dimensions would need to be known, together with any other factors or variables that would cause a change of programme. If the individual values of each of these variables are marked on a selector switch, and a separate selector switch is used for each variable, it is possible to identify completely any required set of conditions by setting these switches correctly.

Considering again the motorized uniselector, it has been stated that any required position can be obtained by using a number of selector switches in conjunction with a corresponding number of levels on the uniselector. If these switches are marked as described in terms of the required programme, each of the fifty positions of the motorized uniselector represents a separate programme, or set of conditions selected by the switch settings. The possible number of combinations can exceed the fifty positions on the uniselector, but many do not correspond to realistic programmes. Allowance can be made both for increasing the number of programmes beyond fifty and also for giving a suitable signal should an unrealistic combination be selected. Thus any required programme can be selected by means of switches marked in terms of input and required dimensions, temperature, type of material and any other factors which would cause a variation of programme.

Programme storage

It will be remembered that a motorized uniselector is effectively a motorized switch consisting of 16 levels of 51 contacts. Thus if a storage uniselector using one

Fig. 1 Diagram of automatic programmer a Programme selection b Programme storage c Pass selection d Output reference
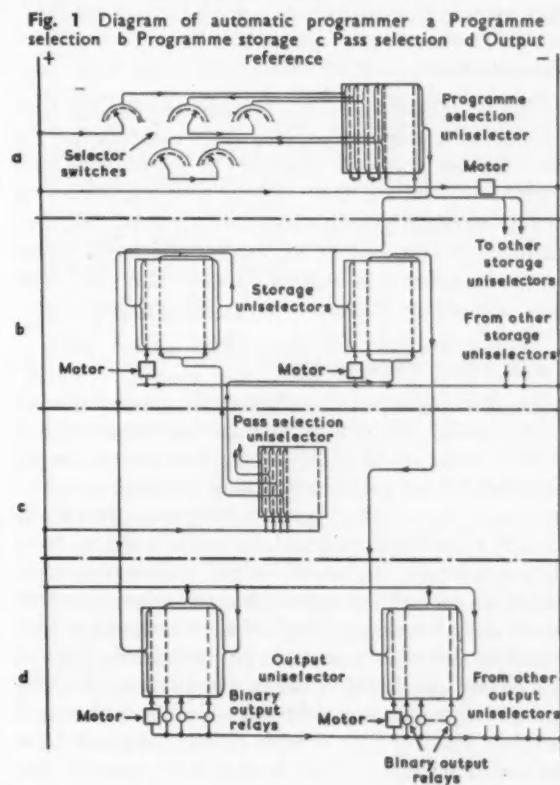
Fig. 2 Uncovered master unit, front and back

marking track only is controlled from the programme selection uniselector previously described, fifteen levels are available for storing the programmes themselves. It will be seen therefore, that a motorized uniselector can store fifty programmes each of fifteen passes, and each of these 750 points represents a stored position or speed reference. Thus a fifteen-pass programme is stored by wiring the fifteen points of the appropriate position on the storage uniselector to the correct fifteen points on the marking level of the output uniselector (see *Digital Output Reference Signal* below).

A separate uniselector is required for each function (screws, manipulators, speed etc.), but these are all controlled or ' slaved ' from the single programme selection, or master uniselector.

Pass selection

One of the fifty possible programmes having been selected, it is now necessary to select consecutively the pass settings for each function. A ratchet-type uniselector is used for this purpose, and the wipers of each programme storage uniselector are connected consecutively to one level on the ratchet uniselector. Thus, as this uniselector is stepped forward once after each pass, succeeding reference settings are obtained.

Digital output reference signal

It will be seen that the effect of the programmer so far is to select, for any one setting, one contact from a total of 750 (i.e. 50 × 15) on the programme storage uniselector. Thus each contact on this uniselector represents any one of many possible reference settings (i.e. screwdown position etc.) and, in order to obtain flexibility, a further motorized output uniselector is included to convert the signal from the selected contact into a digital reference. Each of these contacts is connected to one of fifty contacts on the marking level of this output uniselector. Thus each position of this uniselector represents one reference value, and there are therefore basically fifty possible different values for the 750 stored settings. As will be seen later however, this

output storage capacity can be increased if desired. Each of ten of the remaining fifteen levels on the output uniselector controls a relay, and this in turn represents one of ten binary digits. This ten-binary-digit number constitutes the reference signal for the function con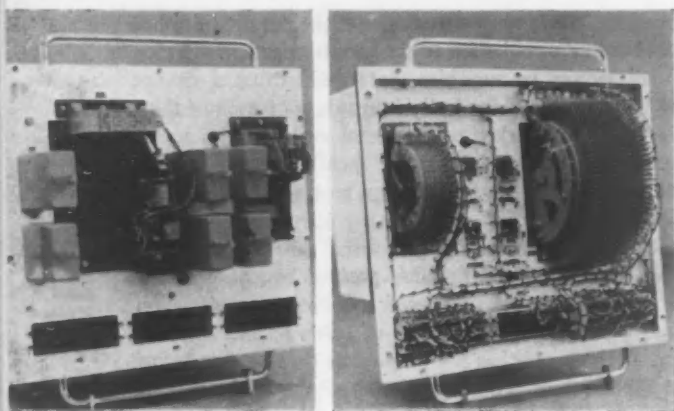cerned, and the value for any particular output uniselector setting is determined purely by the wiring of ten of the fifteen contacts on the relevant position. The digital number can either be converted into a voltage proportional to this number by means of a digital potentiometer, or the number can be used directly by comparing digitally with the servo-loop feedback signal.

Since it is possible to control many programme storage uniselectors (one for each movement being controlled) from one programme selection uniselector, only one such uniselector is required for a complete equipment. Similarly, since there are eight levels on the ratchet uniselector, several storage uniselectors can be scanned pass by pass by one ratchet uniselector.

It would be possible theoretically to combine the action of programme storage and programme selection in one uniselector. Due to the number of levels required for marking from the selector switches, however, this leads to reduced pass storage capacity. In addition it will be appreciated that difficulties arise with regard to standardization.

STANDARD PROGRAMMING UNITS

The equipment described above can be divided conveniently into a number of standard units or ' bricks ' which can be assembled as required for any particular application. Each unit is contained in one of two standard sizes of box, and the uniselectors are vertically mounted with back and front access available for maintenance purposes. Each unit is fitted with plugs, and is mounted by means of a hinge-and-catch arrangement. This facilitates quick removal and replacement should this be required for maintenance or wiring-in of programmes. Dust-proof covers are provided with quick-release fasteners, and visual inspection of the uniselectors is possible through a front window. The standard units themselves are described below.

Programme and pass selection

A complete automatic programmer requires only one programme-selection motorized uniselector and one pass-selection ratchet uniselector. Thus it is logical to mount these in a single box. This selector unit is effectively a master which controls all the other units as slaves. This unit, therefore, selects the programme dictated by the input switches, and selects consecutively the pass settings for the various functions. See Fig. 2.

Programme storage unit

This unit contains all the essential components for storing programmes and output reference settings for one movement or function. Thus for any particular

equipment there would be a number of these units, one for each manipulator, one for the screws, one for the speed, etc. All the units would be controlled as already described, both for programme and pass selection, by the single master unit. The unit therefore contains one programme storage and one output motorized uniselector, together with a tag board to facilitate the wiring-in of new programmes when required. Standard cable forms are provided for this purpose. See Fig. 3.

The unit stores nominally a maximum of fifty programmes of fifteen passes, and gives an output reference in the form of a ten-binary-digit number. However, it often happens that many of the programmes resemble one another closely, and if it is found possible to reduce all incoming pieces firstly to one of two or three standard intermediate sizes, this storage capacity can be greatly increased. After reducing the piece to one of these standard sizes, the programme storage uniselector, controlled by the master unit, can change position automatically to select a sectional programme giving the correct output dimensions. This mid-programme change facility can also be used to change programme during rolling, should this be necessary due to, say, the low temperature of a piece.

Plugboard

Before any programme is wired into the permanent store is is sometimes necessary to carry out experiments to determine the optimum settings for each pass. Plugboards, which are selected by means of the input switches, and which control in turn the relevant output uniselector, are included for this purpose. These plugboards can also be used for programmes which are rarely required, and are therefore not worth storing. See Fig. 4.

Fig 3 Uncovered storage unit, front and back
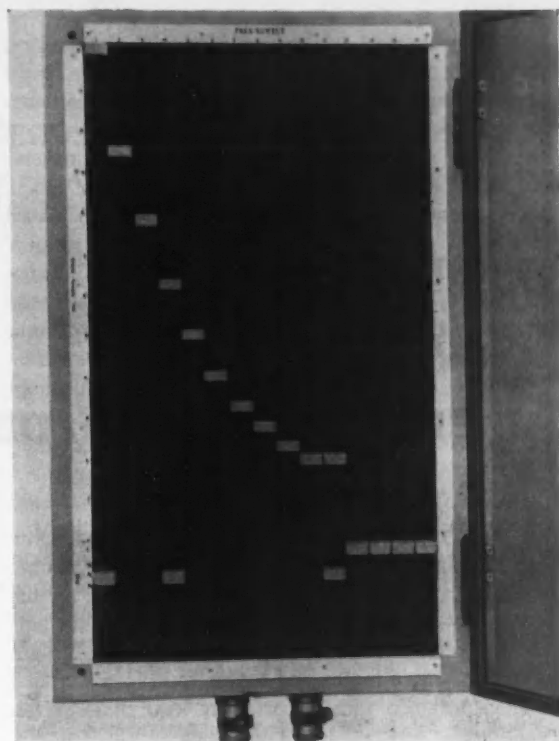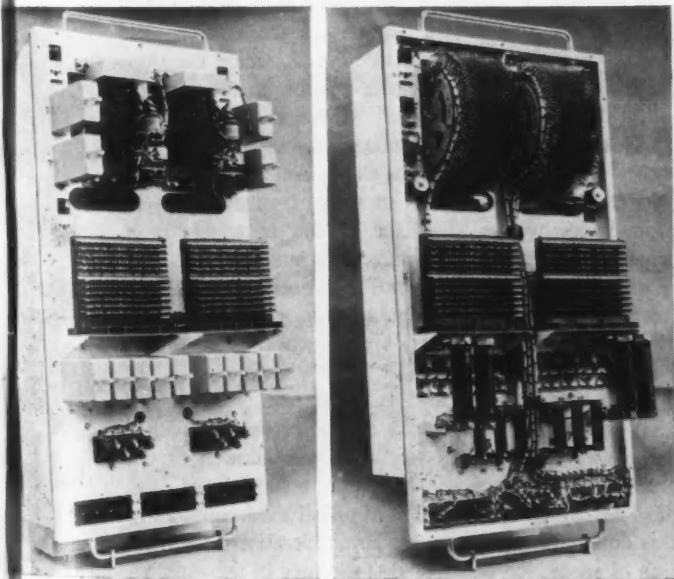
Fig. 4 Plugboard for trial programmes. Up to fifteen passes are possible, with 49 coarse and three vernier settings

Increase of storage capacity

The basic equipment can store fifty programmes of fifteen passes, and can give any one of fifty reference settings selected from a total of 1024. It is often necessary to increase this storage capacity and half-sized auxiliary units are available for a. doubling the number of stored programmes, b. doubling the number of passes per programme, and c. increasing the number of possible reference settings from 50 to 750. The unit used for increasing the number of possible outputs can also be used on its own where a total of only fifteen possible reference settings are required. This unit would be suitable for mill speed control.

Self-contained units

For certain applications the required storage and control facilities are limited and the complete equipment can be accommodated in a single unit. Thus a unit combining the functions of the master unit and storage unit is available. This stores up to eight programmes of 25 passes and gives any one of 750 possible reference settings.

On plate mills it is normal to set each successive screwdown position by subtracting the movement required from the previous setting. That is, the *draft*, as opposed to the *absolute position*, is controlled. A single unit is available which converts the draft selected by the operator into a digital number, and subtracts this from the original screwdown reference signal by means of a relay subtractor.

To be continued
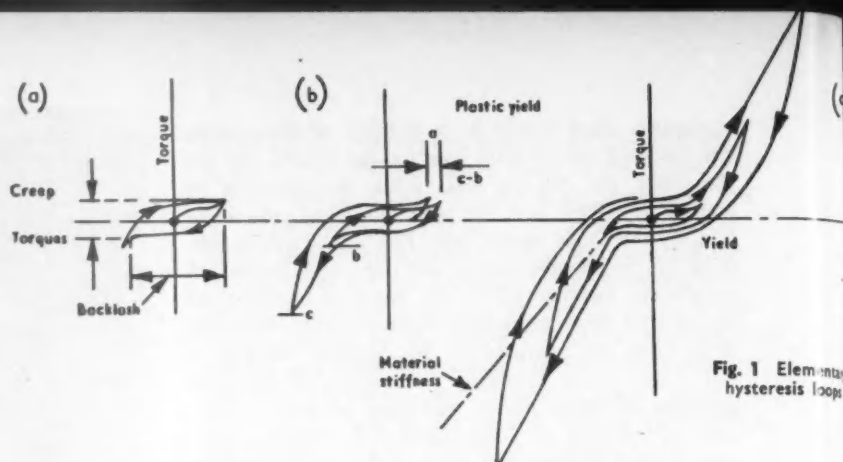
Fig. 1 Elementary hysteresis loops

An engineer's approach to a servo problem

by **HUGH CLAUSEN**, o.b.e., b.sc.(eng.)

THE ANALYTICAL ASPECTS OF SERVO SYSTEMS HAVE been ably and fully dealt with by physicists and mathematicians, and there is an extensive literature on the subject. Few books or papers give much useful guidance in the engineering design stages, such as designing or choosing a motor and a gear train is give a specific performance with a particular load under given conditions.

This paper describes an approach. Properly played it will land you near, if not actually on, the green, where the finer subtleties of scientific putting can be profitably exercised. There are many small servos where these design considerations are not important. I liken these to clock golf on a lawn: one is on the green to start with. There are a greater number of servos, both large and small, where mechanical design is the dominating factor.

Men of powerful intellect have unfortunately tended to concentrate on matters which can be expressed in symbolic terms and to neglect things which cannot be so expressed, in spite of the fact that both are equally important and they both need equal mental powers. Failures are probably less often due to defective science or deviationism in the black box than to the use of the wrong size of nuts and bolts. I am told that the higher intellects naturally draw towards activities which can be precisely expressed. What is more precisely expressed than—say—the cutter spindle and bearing arrangements of a Mikron gear hobber; but how do you express it symbolically?

Tests on existing materials

Some experience is needed before starting on a new design, and we can gain such experience by doing trials with existing material either in reality or in imagination. A design must have reference to a specific problem, and in the case considered the motor has some relationship between its torque and speed, such as does either an electric motor or a valve-controlled hydraulic motor, and the load will have substantial inertia as well as friction. A gun or radar aerial mounting—in which my own

experience has been most direct—provides a typical case covering most servo problems in principle and including the points that occur in other applications. The factors dealt with are completely general and apply to any servo system of any size. The results of the tests outlined below, which have been proved by much experience, will tell one what to look for in performance and what to strive for in design.

Backlash, hysteresis, and resilience

These bugbears are best analysed by a stiffness test. The gear train is locked at the end remotest from the motor (with means for measuring the yield of the locking arrangements), torques are applied at the motor coupling, and the angular yield is measured. Torques are best applied cyclically, in steps, to increasing amplitudes in both directions. The results come out as a series of mechanical hysteresis loops from which backlash, resilience and plastic yield can be effectively separated, as shown in Fig. 1. Referring the torques to the moment of inertia of the driven load, and plotting them in non-dimensional terms as an acceleration/yield relationship, we get curves like Fig. 2, where the slope of a line through the origin is a direct measure of the natural frequency of torsional oscillation.

This diagram is an intimate glimpse into the very heart of the machine, with all its defects and virtues visible at a glance. The servo performance will be dominated by the character of the hysteresis loop, especially if there is any appreciable intertia in the load. Experience shows that natural frequencies derived from these static stiffness tests give results closely matching the figures obtained under dynamic working conditions.

The running-up curve, and its derivatives

If the motor is energized at full power—as with a large error signal in normal use—and allowed to run free we can get a curve of speed as a function of time, such as curve A of Fig. 3. Graphical differentiation of this curve will give us curve B, acceleration as a function of speed, the phase plane trajectory of the running-

up curve. This curve B is an envelope, containing all the possible combinations of speed and acceleration at which *that* motor with *that* load and *that* gearing will run. Servo conditions need a margin of performance of both speed and acceleration, so a smaller envelope such as curve C, will give the limiting conditions under servo control with a permissible error.

How closely the useful servo performance envelope C approaches the free running performance curve B depends on the quality of the servo characteristics, the signal processing arrangements and their performance. Fig. 2 gives the character of the engineering design of the system at a glance, without regard to 'servo' matters, and this Fig. 3 gives the character of the servo system as such; the capacity of the motor for handling its load, and the limits of servo performance. Both diagrams are of fundamental importance, and demand careful study.

Simple harmonic motion tests

A useful way of testing a servo system is by a simple harmonic motion test, the input transmitter being oscillated at a known amplitude and frequency. The simultaneous combinations of speed and acceleration occurring during simple harmonic motion can be represented on the left-hand side of Fig. 3 by a circular or elliptical locus curve, of which one quadrant is shown in curve C.

In simple harmonic motion, $V_{max} = \dfrac{2\pi a}{T}$

and $f_{max} = \left(\dfrac{2\pi}{T}\right)^2 a$

So T is $\dfrac{2\pi V_{max}}{f_{max}}$

And the amplitude a is $\dfrac{(V_{max})^2}{f_{max}}$

Using these equations we can fix the amplitude and frequency which will give us the maximum velocity and acceleration of any envelope line on Fig. 3, and

do a simple harmonic motion test, recording the error signal and its relation to the input. The recorded errors can be plotted as at right-angles to the paper at the appropriate points of acceleration and speed on the relevant curve C of Fig. 3.

This method of presenting the results of simple harmonic or other running tests in their proper relationship to the running-up curve derivatives is of great value. The positional error for any combination of speed and acceleration depends on past events. The same combination of simultaneous values of speed and acceleration can occur with two different simple harmonic motion cycles, such as curves C and F but it is not to be expected that the positional errors at the point of intersection will be the same for both.

Specific performance

Most servo systems are intended to fill certain conditions of speed and accuracy, either simultaneously or with certain maximum running speeds, and a specified accuracy under static or slow running conditions. Most of these are conveniently dealt with as 'steps per second'. There are usually no definite 'steps' but there will be an accuracy figure, the smallest quantity that need be considered, say three minutes of angle for a precision radar mounting. We can call this a step. Twenty degrees per second with three minute accuracy will be 400 steps per second. If five minute accuracy would suffice, this will be 240 steps per second. One soon gets used to the figures: 50 per second is easy, 100 is pretty good, 250 is very high, and I have not yet seen a servo working at 1000 steps per second, though this may well be possible.

The reciprocal of steps per second gives a time, which can be considered as the effective time-constant of the system, linked to the quantities shown in Fig. 2 and Fig. 3. If the structural stiffness, for example, corresponds to only about 3 or 4 c/s one cannot expect a high performance. Curve A of Fig. 3 will approximate to an exponential curve with a time-constant equal to final velocity/initial acceleration. This time-constant clearly limits the rate of response to rapid changes in the input.
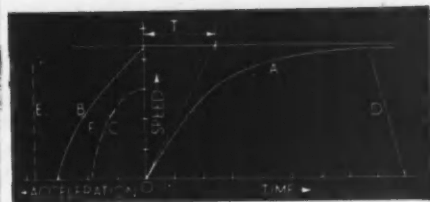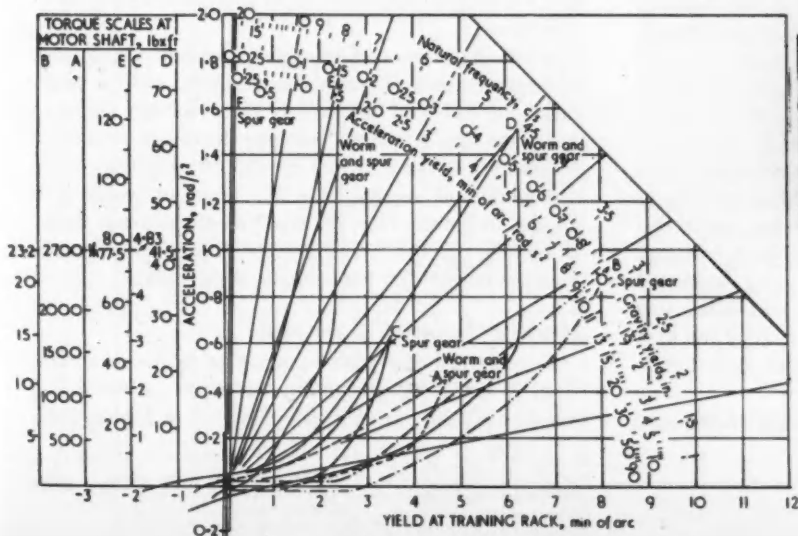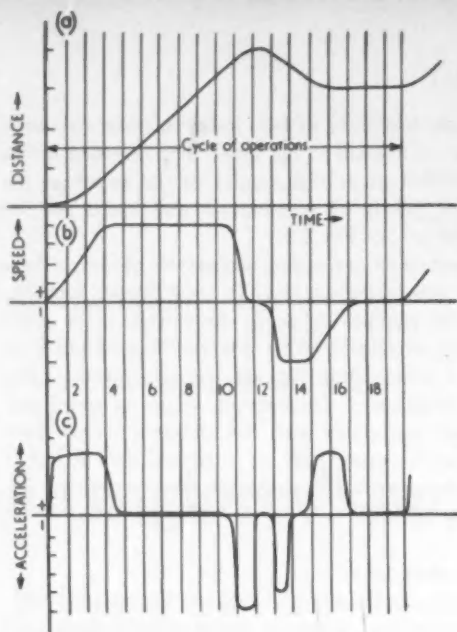

Fig. 3 Running-up curves and their derivatives

Fig. 2 Typical hysteresis loops

Fig. 5 Duty cycle analysis

Note: Point 13 is doubtful
Point 11 is a 'retardation' point

Fig. 6 Motor and load characteristics

Fig. 4 Typical duty cycle

Design of a new system

The design of a new system is usually rather a cut and try business. The gear to be controlled may be in existence, and we must make the best of it somehow, or there may be only a limited range of types and sizes of motor available. A duty cycle, or time programme of performance is the necessary starting point. It might take the form of Fig. 4a, a time programme of distance as a function of time, or b, speed/time. We also need an acceleration/time curve, obtained by differentiating b once or a twice. Splitting this diagram up into vertical strips, we get for each strip simultaneous values of speed and acceleration. These can be plotted, one for each strip, on a diagram like Fig. 5. These can all be plotted together, remembering that points of retardation must be considered in conjunction with the ' braking' curve of Fig. 3.

An envelope can be put round these points, or as many as may seem necessary. This envelope, giving us maximum values of speed and acceleration, is one of the performance curves C of Fig. 3, and we must now choose or design a motor whose character is such that we shall get this performance under servo conditions allowing for all the effects of friction and inertia of the driven load, the gear ratio used, and the efficiency of the gearing. The free running envelope, curve B, must have a sufficient margin to do this.

First steps

We start with the mechanical design. If the gear is in existence we do some stiffness tests on it, and plot some hysteresis loops. If not we must look carefully at the detail drawings of the whole system, estimating what will be the response of each component. We lock up the final drive, or take the gear up to its stops, and apply torques to turn the motor further. What sort of a ' wind-up' do we get? What will this torque look like when translated into acceleration and plotted on a diagram like Fig. 2?

These matters—the necessary starting point—are hardly possible to calculate. Judgment based on experience will be needed. Experience soon builds up from trials of available material. There is a tendency to put the control system, and signal processing components into a different category from the ironmongery that are intended to control, but the whole system from end to end is one thing, and must be considered as such. In particular, is the linking up point between two separate elements, possibly made by different firms to different sets of drawings, with different tolerance systems, perfectly clear to all concerned as to exactly what is intended? Changes in layout or mechanical design are difficult to deal with after manufacture. Some early applications of servo control to machine tool drives showed lack of appreciation of the overall dynamics of a servo problem. A mechanical layout well suited to hand control may be a failure under servo conditions.
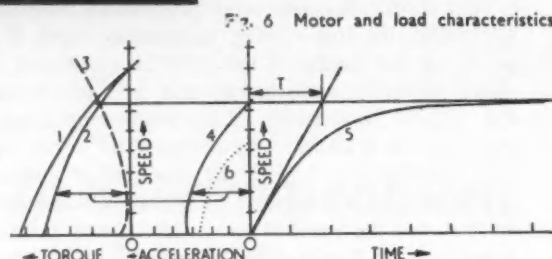
A proper order of approach must be made—the known factors are the load conditions and the performance required. The system must be designed to suit them, working backwards from the known to the unknown. If the load conditions are not known we have no starting point, and something must be assumed. What follows will depend on our assumption. No design can be taken for granted. Gearing quite suitable for hand control may be utterly unsuited for servo operation.

Is the structure stiff enough to prevent the storage of large amounts of strain energy on the sudden application of full load torque? Is there enough metal to carry the strain energy resulting from an occasional oscillation? Is the structure capable of sufficiently rapid distribution of energy from the point at which it is applied to prevent local damage? Resonance may occur, if only for one cycle, and involve stresses much greater than the normal full load torque of the motor.

Matching the motor to the load

Figures of motor performance give torque as a function of speed. A gear efficiency figure gives the net torque available, as in curves 1 and 2 of Fig. 6. Fric-

tional or working load torque at the load spindle, referred to motor shaft value, is shown in curve 3. The difference between 2 and 3 is the torque available for accelerating the load, and the intersection of these two gives the maximum free running speed of the system. Curve 4 is acceleration torque as a function of load speed, plotted as load acceleration as a function of load speed. A simple graphical integration gives us the free running-up curve of our new system, integrating the relationship between speed and acceleration of curve 4 into that between speed and time, curve 5. This is our designed performance which we expect to get on trial; and it remains to be seen whether the performance envelope E of Fig. 5, derived from the duty cycle, falls far enough below this new derived free running envelope, 4 of Fig. 6, to give us the performance we need. Some judgment will be needed here, depending on the character, and performance needed, of the system as a whole. Twice the maximum power represented by the time programme of performance gives a good starting point. Where accuracy is only expected under static, or very low speed conditions a smaller margin will suffice, but the stiffness/inertia ratio should be maintained, to prevent damage by random movements of the input transmitter.

Gearing

Many factors are involved in the best ratio between motor and load. The motor speed at which it gives its maximum output should be somewhere near that at which it will run when the driving power required is greatest. It is also good to have a high acceleration available, i.e. a reasonably optimum ratio of motor torque/system inertia. The maximum occurs when the referred inertias of motor and load are equal; but it is not at all critical. Large changes, such as may be needed to enable the motor to run most frequently at

Fig. 7 Gear ratio and torque/inertia ratio. The Actual/ max. possible Torque/inertia ratio $R = 2p/(1 + p^2)$, where P is the actual gear ratio $\sqrt{Q}$, where Q is the ratio of load inertia to motor inertia, each about their own axes
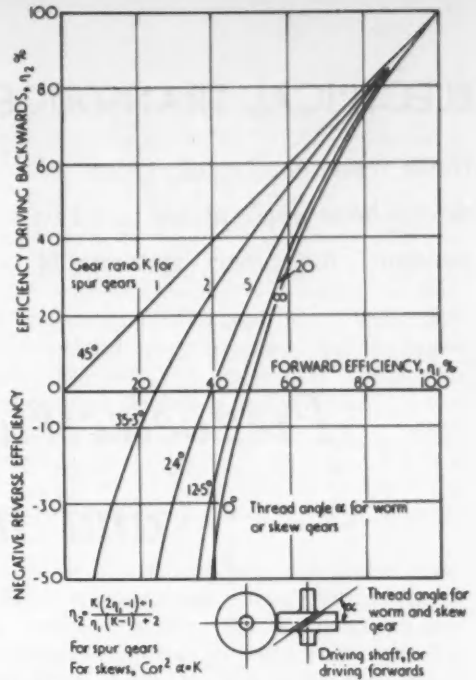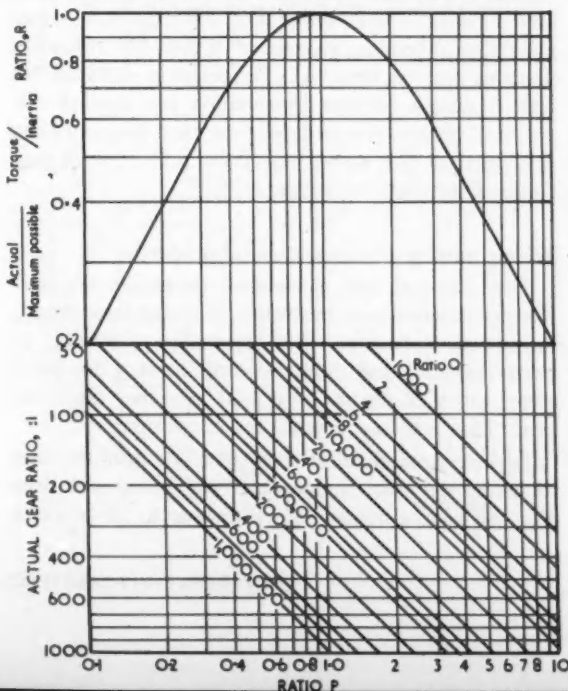
Fig. 8 Forward and reverse efficiences of gearing

its maximum efficiency, or at speeds where it can give its maximum output, can be made without much change in the torque/inertia ratio. Fig. 7 gives a useful analysis of the effects of changes in the gear ratio.

The best arrangement of gearing is not necessarily that which gives the minimum inertia. Stiffness and efficiency are usually the dominating factors. Every gear mesh involves some loss in both, and gear wheels should be as large as possible with pinions as small as possible, so as to have the smallest number of gear meshes. Only experience of good design can tell what kind of gearing and framework is needed for a good performance. There is not much guidance in industry, but *modern* machine tool design gives some help. Experience soon builds up from tests of existing material. The gear wheels themselves are often the part needing least attention, as good experience is available. The major problem will be the structure as a whole, methods of securing gear wheels to shafts, bearings, and bearing supports.

High efficiency gearing is essential with any inertia load, to deal with the free flow of energy between motor and load which accompanies any changes of speed. Lack of reversibility will result in rapid wear and poor performance. Worm and skew gears always have lower efficiencies and wider hysteresis loops than spur gears. They should never be used unless there is some special reason. The relationship between forward and reverse efficiency of gearing is worth study. Fig. 8 gives some useful figures, and there is a fairly complete analysis available in the literature.

ELECTRICAL TRANSDUCERS—8

These two analogous types of
device have applications to many
dynamic measuring instruments

Piezoelectric
and magnetostrictive elements

by **R. E. FISCHBACHER,** B.SC., A.R.C.S.T., A.M.I.E.E.

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THE TERM 'PIEZOELECTRIC' IMPLIES BY ITS DERIVATION
a relation between pressure and electrical effects. It is
applied to materials in which pressure produces an
electrical charge. The effect is reciprocal, so that if a
charge is induced across a piece of material, it will
distort as though pressure had been applied. A con-
siderable number of materials exhibit this effect, prob-
ably the best known being quartz. Most of these mater-
ials are crystalline, but more recently a new range of
materials has come into use—namely the *ferroelectric
ceramics*.

It will be convenient to include a description of mag-
netostrictive devices, since these exhibit a relation be-
tween dimensional and magnetic effects.

Both piezoelectric and magnetostrictive transducers
find many applications in instruments (chiefly ultra-
sonic), but also in many other fields.

Piezoelectric materials

The most ubiquitous of the piezoelectric materials is
quartz, which finds application in frequency and time
standards because of its incomparable physical stability.
Rochelle salt is much used in gramophone pick-ups
owing to its high electromechanical coupling coefficient.
Ammonium dihydrogen phosphate (a.d.p.) has been
widely used in high-power ultrasonic transducers for
underwater detectors. Ethylene diamine tartrate (e.d.t.)
and dipotassium tartrate have been used in electro-
mechanical filters at low radio frequencies. Many other
crystalline materials exhibit the piezoelectric effect and
are used in various applications. More recently the
ferroelectric ceramic materials have been developed.
Amongst these the most promising are barium titanate
(already in wide use), lead zirconate and lead meta-
niobate.

The term 'ferroelectric' is a misleading one since
these materials contain no iron. It is derived by analogy

between the properties of these materials and those of
ferromagnetic materials.

The domain theory of ferromagnetism visualizes
ferromagnetic materials as being divided into a large
number of 'domains' within each of which the mag-
netic moments of all particles are aligned. In the un-
magnetized state the domains are randomly orientated,
and the application of a strong magnetic field causes
reorientation of the domains or selective growth of
favourably orientated domains until they are predom-
inantly aligned in the same direction. The piece of
material then behaves as a permanent magnet. The
theory also explains the magnetic phenomena of satura-
tion, remanence, hysteresis and coercive force.

Analogous properties are found in the ferroelectric
materials. The existence of domains within which there
is a unidirectional electric polarization can be demon-
strated. If such material is heated above its Curie point
and allowed to cool under the influence of a strong
polarizing potential, growth of favourably orientated
domains can be observed. Ferroelectric materials ex-
hibit hysteresis between polarization and applied volt-
age, and permittivity is dependent upon frequency and
field strength, just as permeability is a function of these
factors in magnetic materials.

Widely varying electromechanical properties

The electrical and mechanical properties of piezo-
electric materials are insufficient to define their electro-
mechanical behaviour. With crystalline elements, the
elastic modulus and dielectric constant vary depending
along which of the major crystal axes they are meas-
ured. That is to say, crystals are anisotropic.

Two electromechanical coefficients are normally used
to define the electromechanical properties, and these
also will have a number of values—up to 18—depend-

TABLE I

PIEZOELECTRIC MATERIAL	CUT	MODE	DIELECTRIC CONSTANT ϵ	ELASTICITY MODULUS Y NEWTON/M²	COUPLING COEFFICIENT k, %	FIELD OUT / STRESS IN g, VM/NEWTON	STRAIN OUT / FIELD IN d, M/V	FREQUENCY CONSTANT C/S X M	MAX. SAFE TEMPERATURE, °C
				$\times 10^9$			$\times 10^{-12}$		
Quartz	X	Thickness	4·5	80	11	0·058	2·3	2890	550
Barium titanate		Thickness	1200	110	46	0·013	140	2750	80
Lead zirconate		Thickness	1350	83	35	0·011	133	2000	300
Rochelle salt	45° Y	Expander	9·4	10	29	0·330	27	1180	45
A.D.P.	45°Z	Expander	15·3	19·3	29	0·177	24	1680	120

ing on the direction of measurement relative to the principal crystal axis.

The first of these constants, usually designated d, is the ratio of strain of the element to the applied electric field. The second, g, relates to the ratio of the open-circuit voltage to the applied pressure. Both constants may appear with subscripts, e.g. d_{33}, g_{31}, which denote the axes to which they refer.

A further coefficient of the material is of importance. This is the electromechanical coupling coefficient k. This constant is related to the piezoelectric constants and to the elastic modulus Y by the relation $k = \sqrt{(dgY)}$. The coupling coefficient is defined as the square root of the ratio of the energy stored in mechanical form to the total stored energy at a low frequency.

The interaction between electrical and mechanical features of the transducer implies that its mechanical behaviour can influence its apparent electrical characteristics. Its equivalent electrical circuit is shown in Fig. 1a, in which C_0 represents the capacitance of the crystal itself when it is mechanically constrained, e.g. rigidly clamped. L, C and R represent in electrical terms the mechanical behaviour; L is dictated by inertial effects, C by compliance of the crystal, and R by internal frictional loss and energy dissipation in the load. Energy stored in C_0 is stored in electrical form, whereas energy stored mechanically may be considered to be stored in

C. At low frequencies the two capacitors C and C_0 are effectively in parallel across the input, and the stored energies are $\frac{1}{2}V^2C$, and $\frac{1}{2}V^2C_0$ respectively. The electro-mechanical coupling constant is then given by

$$k^2 = \frac{\frac{1}{2}V^2C}{\frac{1}{2}V^2C_0 + \frac{1}{2}V^2C} = \frac{C}{C_0 + C} \simeq \frac{C}{C_0}$$

when C is very much smaller than C_0, as is generally the case.

The transducer can be seen from this circuit to exhibit two electrical resonances, one a parallel resonance and one a series resonance. The impedance as seen from the electrical terminals therefore varies with frequency, as shown in Fig. 1b. The information obtainable from this graph can be used to determine k, since

$$k^2 = \frac{\pi^2}{4} \frac{\Delta f}{f_r}$$

where Δf is the difference between the series resonant frequency f_r and the parallel resonant frequency f_a.

Table 1 gives the constants for a number of common piezoelectric materials. Note that the piezoelectric constants indicate voltage sensitivity of the materials and do not imply that the power efficiency of one material as an electromechanical transducer is greater than another. Since, however, in many applications the voltage into or out of the transducer is of great importance the values of these three constants enable decisions to be made as to the most suitable material to employ in any given case.

Magnetostriction

If a rod of ferromagnetic material is brought into a magnetic field parallel to its axis, its length will change slightly. This change may be an expansion or a contraction, depending on the nature of the material, its previous treatment, its temperature and the degree of magnetization. The effect is known as magnetostriction.

Pronounced magnetostrictive effects are shown by iron, nickel and cobalt. Nickel shows the largest magnetostrictive effect of the pure metals but even here the effect is small, amounting to about 40 parts per million. Fig. 2 shows the fractional change in length of several metals with varying field strength. Sintered ferrites also exhibit magnetostrictive effects, and are likely to come into increasing use. As with piezoelectricity a reciprocal effect, known as the *Villari effect*, is found. When stress is applied to the rod in a magnetic field, a change in magnetization occurs.

There is, therefore, a considerable similarity between the piezoelectric and the magnetostrictive transducer; in
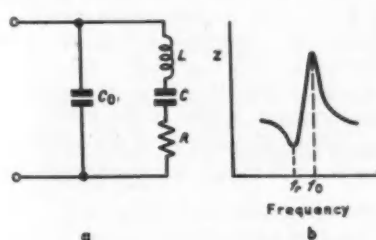

Fig. 1 a Equivalent electrical circuit of a piezoelectric crystal
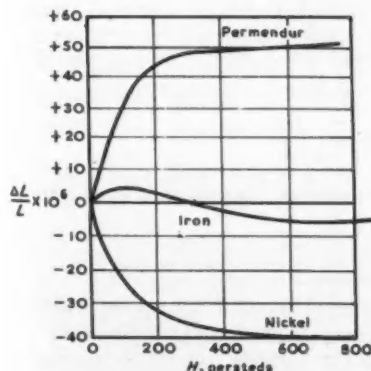b The series resonant frequency f_r and parallel resonant frequency f_a

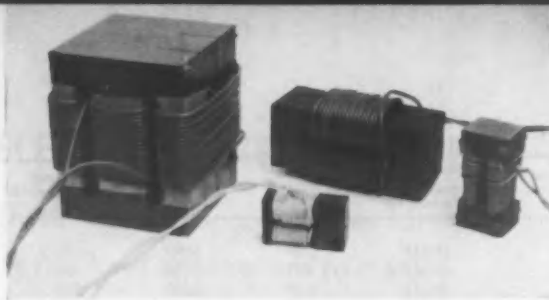Fig. 2 Fractional change in length of metals experiencing magnetostriction

Fig. 3 Transducers made of laminated magnetostrictive material

one there is a relation between dimension and electric field, and in the other between dimension and magnetic field. Since the magnetic field for a magnetostrictive transducer is provided electrically, the electromechanical behaviour of the two types of transducer are closely allied, although the ranges of applicability may differ.

Types of application

Piezoelectric transducers are not basically suited to static measurement. A charge, induced in the element face by the sudden application of pressure, immediately begins to leak away at a rate determined by the capacitance of the element and the resistance between faces. Although most piezoelectric materials are reasonably good insulators, and some are very good, the time-constant (the product of capacitance and resistance) is usually small. Careful choice and preparation of elements may result in a time-constant of a minute or two being achieved, but in practice the piezoelectric transducer is used for dynamic measurement only.

Two classes of dynamic operation may be considered—aperiodic and resonant. In gramophone pick-ups, crystal microphones and accelerometers non-resonant transducers are necessary, and careful design is required to avoid approaching resonance. In most ultrasonic applications, however, the element is operated in the resonant condition.

Many of the ultrasonic applications are of interest to the control engineer; examples are viscometry, thickness gauging, flaw detection, level detection, consistency determination and flow metering. Applications not having direct concern with measurement and control include emulsification, cleaning, soldering, drilling and echo-sounding.

The resonant transducer

Crystals are normally operated at resonance since the amplitude of oscillation for a given excitation is much greater at resonance than away from it. The free crystal will resonate mechanically at the frequency at which

Fig. 4 The mounting of an ultrasonic crystal radiating into a liquid depends on whether the crystal and liquid can safely be brought into contact. Three methods of mounting are shown here
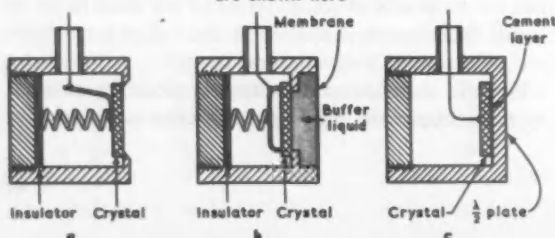
the appropriate dimension t is one half-wavelength or odd multiples of one half-wavelength,

i.e. $t = \dfrac{(2n-1)\lambda}{2}$ where n is integral.

But $\lambda = c/f$, where c is the velocity of propagation of sound in the crystal. Therefore the resonant frequency $f_r = c(2n-1)/2t$.

Usually n is 1, and the crystal resonates at its fundamental frequency, in which case $f_r = c/2t$. From this is derived the frequency constant $c/2t$, which is often quoted for piezoelectric materials.

When very high frequencies are required, the crystal plate may become too thin to be practical. It may then be more feasible to use a thicker crystal oscillating in a higher mode.
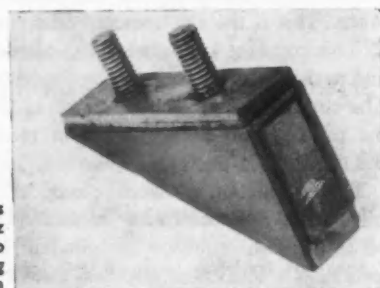
Fig. 5 A 5-Mc/s shear-mode quartz crystal cemented to a prism producing an ultrasonic beam

In considering the velocity of propagation of sound, we must differentiate between two types of wave. For longitudinal or compressional waves the direction of particle motion is the same as the direction of propagation, while for shear waves the particle motion is normal to the direction of propagation.

The velocity of longitudinal sound waves c_l is given by the relation

$$c_l = \sqrt{\left[\frac{E}{\rho} \cdot \frac{1-\sigma}{(1+\sigma)(1-2\sigma)}\right]}$$

where E is Young's modulus, σ is Poisson's ratio and ρ is density. This value, however, applies to the material in bulk. A long bar whose diameter is of the order of half a wavelength or less will have a sound propagation velocity

$$z_l = \sqrt{\frac{E}{\rho}}$$

The velocity of propagation of shear waves c_s is given by

$$c_s = \sqrt{\frac{G}{\rho}}$$

where G is the shear modulus. The value of c_s is generally about half that of c_l.

Quartz and barium titanate

The velocity of sound of longitudinal waves in the X-axis direction in quartz is $5 \cdot 75 \times 10^3$ m/s. The thickness of a 1 Mc/s X-cut crystal will therefore be

$t = (5{\cdot}75 \times 10^3 \times 10^3)/(2 \times 10^6) \text{ mm} = 2{\cdot}87 \text{ mm}$. The velocity of shear waves in quartz is lower, and a Y-cut crystal oscillating in shear at 1 Mc/s would be 2 mm thick.

The velocity of sound in barium titanate is a little less than that in quartz ($5{\cdot}5 \times 10^3$ m/s against $5{\cdot}75 \times 10^3$ m/s) and elements of this material are proportionately thinner at a given frequency. The dielectric constant of barium titanate is, however, very much greater than that of quartz—about 1000 as against 4·5. The value of C_0 in Fig. 1 is very high for a barium titanate element; for example a 2-cm-diameter disk resonant at 2 Mc/s has a capacitance of about 1200 pF. Since the thickness of the element decreases with increase of resonant frequency, and the capacitance correspondingly increases, it becomes increasingly difficult to drive the barium titanate element at high frequencies. The corresponding quartz element would have a capacitance of about 50 pF, but on the other hand its dynamic impedance is very high.

The choice of the most suitable piezoelectric material is dictated by considerations of frequency of operation, temperature and acceptable impedance limits. Ultrasonic measurements have been made as high as 500 Mc/s, but in most practical applications are below 15 Mc/s, at which frequency quartz is most often used.

Magnetostrictive transducers are useful at lower frequencies

Since magnetostrictive transducers depend upon the generation of fairly intense magnetic fields for their operation they find their application at the lower frequencies where such fields can more readily be produced. Such transducers are very robust and can handle large powers. Powers of several kilowatts can be employed at frequencies up to several hundreds of kilocycles per second.

Typical magnetostrictive transducers are shown in Fig. 3. They are constructed from laminations of a suitable magnetostrictive material, and the dimensions are chosen to obtain the desired resonant frequency. The adoption of a laminated construction reduces eddy current losses.

The Q-factor of resonant transducers depends upon the mechanical loading imposed upon the radiating face. A quartz crystal suspended in vacuum may have a Q of many thousands. When loaded with water on both faces Q drops to the region of 10, and when loaded with quartz or mercury falls further to the region 1-2.

Fig. 6 An exploded view of a 1-Mc/s ultrasonic transducer designed to operate in water
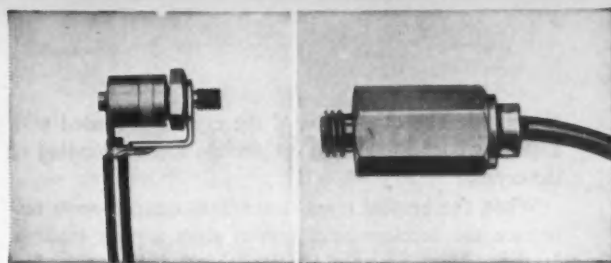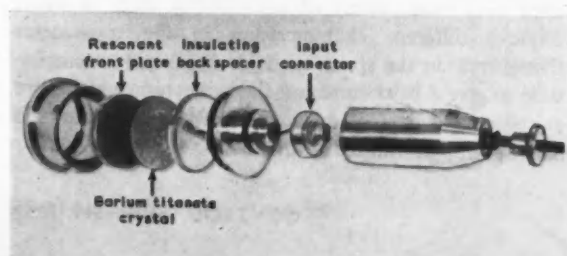
Fig. 7 Typical piezoelectric accelerometers

Mounting the crystal

The method of mounting the crystal depends greatly on the application. Quartz crystals used for frequency control are carefully suspended in vacuum (where possible at nodal points) to avoid constraint. In most applications, however, it is required to couple the crystal to some other solid or liquid medium.

Where the crystal is required to radiate into a solid, it is usually cemented directly to it. Alternatively, a liquid film may be interposed between the crystal and the solid, spring pressure retaining the crystal in contact with the solid. Oil films are widely used to ensure good acoustic contact. Where a cement layer is used, it should be as thin as possible, and the cement should preferably be of a solventless type (e.g. a thermosetting resin) since the evaporation of the solvent may leave voids.

When working into a liquid in which it is permissible to immerse the crystal face, an arrangement such as that shown in Fig. 4a is possible. Where the crystal cannot come into contact with the liquid because of corrosive or other deleterious effects, a barrier may be interposed. A thin metallic membrane can be used (Fig. 4b), provided its thickness is very small compared with the wavelength of sound in the material. The space between membrane and crystal is filled with a suitable liquid. Alternatively a metallic barrier whose thickness is an integral number of half-wavelengths may be used, with the crystal cemented to the rear face (Fig. 4c). Figs. 5 and 6 show two forms of crystal mounting for use in ultrasonic transducers.

When it is required to ensure that the crystal should be damped as heavily as possible a damping load is sometimes used as a backing to the crystal. Various designs for such damping loads have been produced. For example, an epoxy resin loaded with fine tungsten powder provides a good damping load for barium titanate crystals.

Aperiodic transducers

Applications in which it is required that the transducer should not preferentially detect signals of one particular frequency, but should be equally responsive to stimuli over a wide frequency band, include accelerometers, gramophone pick-ups and crystal microphones. In such cases the transducer must operate away from its resonant frequency.

Typical accelerometers are shown in Fig. 7. The piezoelectric crystal is mounted on a base-plate which can be attached to the body whose acceleration is to be

measured. The other face of the crystal is loaded with a mass whose function is to provide inertial loading of the crystal.

When the inertial mass comes into quarter-wave resonance the accelerometer output gives a peak reading. It must therefore be operated well below this frequency. As there is inevitably considerable coupling

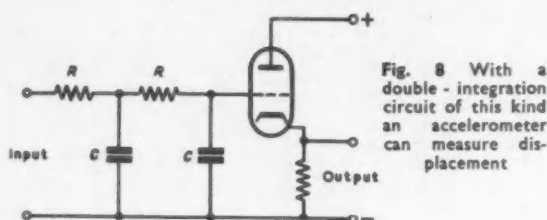**Fig. 8** With a double-integration circuit of this kind an accelerometer can measure displacement

between longitudinal and lateral modes, the cross-sectional dimensions must also be such that they are well removed from resonance in the operating band.

Since acceleration is the second differential of displacement, accelerometers can be used to measure displacement by performing the appropriate integrations of the output. By proper choice of values for R and C, the basic circuit of Fig. 8 can be adapted to indicate displacement over limited frequency ranges. Velocity can likewise be obtained by using a single stage of integration.

The output of the barium titanate accelerometers in Fig. 7 is about 15 mV/g, where g is the acceleration due to gravity, over the frequency range 20–20,000 c/s.

In crystal microphones and crystal pick-ups a type of element known as the *bimorph* is used. This consists of two thin piezoelectric elements cemented together as shown in Fig. 9. If a bending moment is applied as shown, the upper crystal is in tension and the lower crystal is in compression. Charges of appropriate polar-
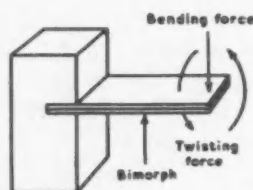

Fig. 9 The bimorph —here shown subject to a bending moment—is used in crystal microphones and pick-ups

ity are developed on the crystal faces. If the two elements are of opposite polarity, a potential will appear between the faces on the application of the bending moment.

Bimorphs are also used in a torsion mode and because of the much higher compliance that can be achieved in this mode of operation these twister bimorphs are widely used in gramophone pick-ups. In crystal microphones a diaphragm is coupled to the bimorph. Rochelle salt and barium titanate are probably the materials most widely used in these applications.

Information storage

The hysteresis displayed by ferroelectric materials may be employed for information storage. The polarization applied-voltage curve exhibits hysteresis as Fig. 10 shows for a single crystal of barium titanate. These crystals are very small and a considerable number can be assembled very compactly to form a binary store.

The operation of such a store is very similar to that of a magnetic store. The object is to store one of two bits of information, representing the digits 0 and 1, and to be able to read out which digit has been stored. In the absence of applied voltage, it will be seen from Fig. 10 that there are two possible states of polarization marked 0 and 1. The state of the crystal at any time will depend on its immediate past history. Suppose a positive storage pulse has been applied. Provided the pulse has exceeded the saturation level in the positive direction, the state of polarization after the pulse has ceased is that labelled 0. A 0 digit has now been stored. When reading out from the store a reading pulse of positive polarity is applied. The crystal is taken into saturation in the positive direction once more, and
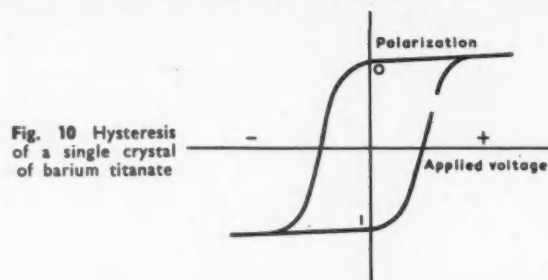
Fig. 10 Hysteresis of a single crystal of barium titanate

returns to state 0. During this time a small current pulse flows.

Suppose, however, that a negative pulse is applied, taking the crystal round the hysteresis loop to saturation in the negative direction. After the removal of the pulse, the polarization will remain in state 1, storing the digit 1. When the positive reading pulse is applied this time, the crystal traverses the loop in the positive direction and returns to state 0. This change of polarization is accompanied by a much larger current pulse. Thus the reading pulse distinguishes the two states of the crystal. In the process of reading out, the stored information is, of course, removed and further circuits are required to replace it if this is needed. The access time of such store need only be of the order of 10 μs, and the power consumption is considerably less than for ferrite stores.

Conclusion

Piezoelectric and magnetostrictive transducers are used in a wide variety of applications, each of which requires different characteristics in the transducers themselves. In the space available it has only been possible to give a brief survey of the subject, on which there exists a great deal of detailed literature for those who have specific transducer requirements.

Graphical techniques

for control systems—2

N. G. MEADOWS
Wimbledon Technical College

THIS DATA SHEET PRESENTS A BRIEF outline of the use of the Nyquist diagram when gain adjustment and series compensation procedures are to be used to obtain a desired system response.

Gain adjustment : use of M circles

Fig. 1 shows the basic M circle relationships, where OB is drawn tangentially to the circle. Clearly $\varnothing = \sin^{-1}(1/M)$ where $M = |\theta_0/\theta_1|$ To adjust gain for a specific M value the following procedure is adopted

a. Plot open loop locus $KG(j\omega)$ for unity gain $(K = 1)$, as in Fig. 2.

b. Draw line OA of slope $\varnothing = \sin^{-1}(1/M)$ using the graph of Fig. 3 to determine $\varnothing$.

c. By trial draw the M circle on the negative real axis which is tangential to the line OA and the $G(j\omega)$ locus.

d. Draw a straight line from the point of tangency of the M circle and line OA to meet the negative real axis perpendicularly at B. Then the correct gain for the prescribed condition is $K'=1/OB$ and the necessary gain change can now be assessed with respect to the original gain. The point of contact of the M circle with the $G(j\omega)$ locus gives the resonance frequency ω_r. This should be compared with the requisite value and if unacceptable further M values can be assigned. Should this not be permissible gain adjustment must be replaced by a phase compensation procedure. Recourse may be had either to series or parallel compensation methods.

Series compensation

If two elements of a system do not impose mutual loadings when connected in cascade, the overall
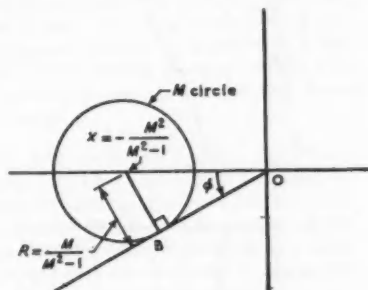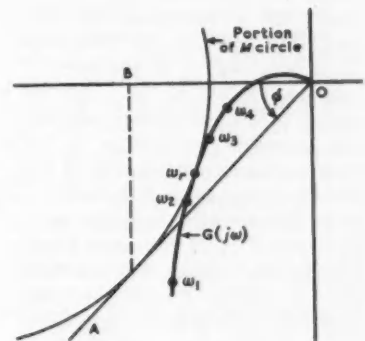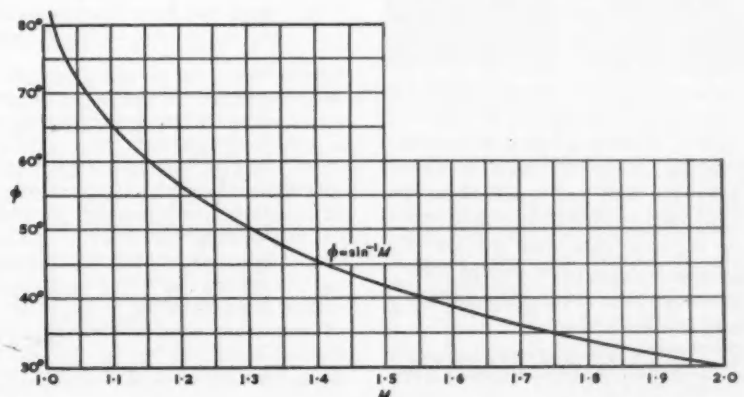

Fig. 1 M circle relationships

Fig. 2 Assessment of gain value of specified M value

Fig. 3 Angular inclination φ of line OA for varying M values. Note : φ is measured counter-clockwise from the negative real axis

transfer function of the cascaded elements is the product of the separate transfer functions. If these are respectively $AF(j\omega)$ and $KG(j\omega)$, at any one frequency ω_1 these will reduce to expressions of the form $R_1e^{j\phi_1}$ $R_2e^{j\phi_2}$, with a product value of $R_1R_2e^{j(\phi_1+\phi_2)}$. Hence to compound Nyquist loci vector magnitudes for corresponding ω values on the separate loci are multiplied and respective phase angles added; the procedure is illustrated in Fig. 4. The open loop frequency response loci for a d.c. split-field motor and a phase advance network are shown. It is proposed to use the motor in a position control scheme and a reduction in gain is rejected as imposing unwarranted restrictions on transient response and velocity lag. The uncompensated phase margin is 34°, and from Fig. 3 of Data Sheet 8 (1) the associated damping ratio ξ is about 0·3, indicating a highly oscillatory response. The effect of the phase advance network is considered by compounding the two loci. One point on the composite locus is shown at a frequency ω_1 such that $\overline{OC} = \overline{OA} . \overline{OB}$. Using the vector product procedure outlined the complete locus θ_o/e is as shown. The d.c. attenuation of 0·2 for the phase advance network is offset by increasing amplifier gain by a factor of 5, this effect being most readily considered by rescaling the -1 point as the point -5, so that $-0·2$ units of the original scale of A' becomes the -1 point for the compensated locus. The phase margin is now approximately 68° giving $\xi \doteq 0·76$, with a less oscillatory response. This procedure will not necessarily give optimum performance, further trial assessments with varying A_1 and other gain values, in conjunction with the use of M circles, may be necessary. To facilitate rapid drawing of M and N circles, graphs giving X and Y coordinates are plotted in Figs. 5 and 6. A more detailed procedure for the design of phase advance networks will be described in a later data sheet on Bode diagrams. In the next data sheet the use of inverse Nyquist plots, parallel compensation and multi-loop systems will be discussed.

Reference :
1. Dudgeon, D. R.: ' *Data Sheet 8*, Estimating damping ratio for frequency response ' CONTROL, 1959, *8*, p 79

SPLIT-FIELD MOTOR
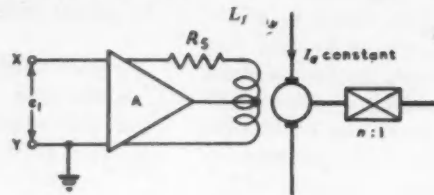
$$\frac{\theta_o}{e_1} = \frac{K_t An}{j\omega(j\omega T_1+1)(j\omega T_2+1)}$$

K_t = motor shaft torque/field current unbalance

$$T_1 = \frac{J}{D} \qquad T_2 = \frac{L_f}{R_s}$$

COMPENSATION NETWORK
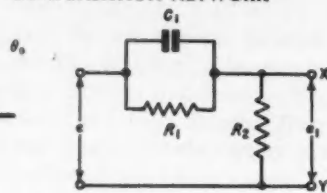
$$\frac{e_1}{e} = \frac{A_1(1+j\omega T_2)}{(1+j\omega A_1 T_2)}$$

$$T_2 = C_1 R_1$$

$$A_1 = \frac{R_2}{R_1+R_2}$$
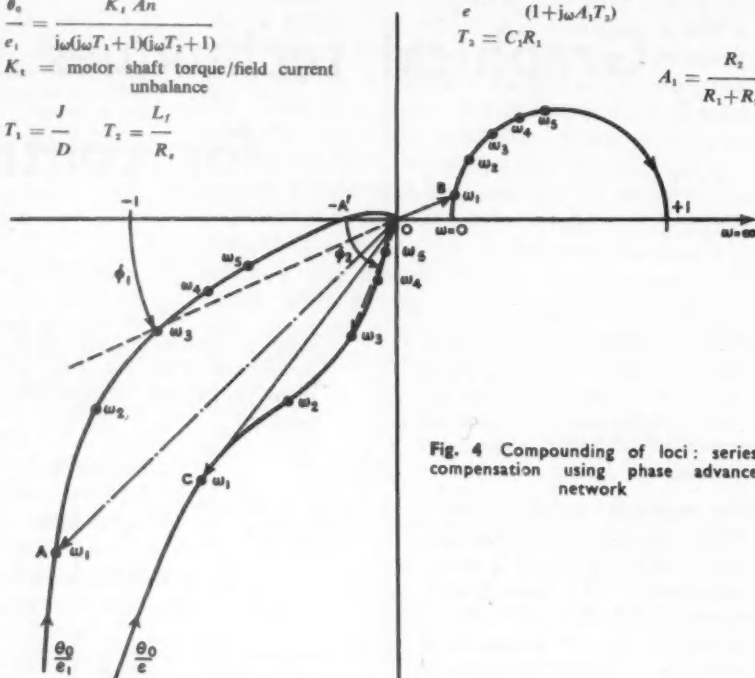
Fig. 4 Compounding of loci : series compensation using phase advance network
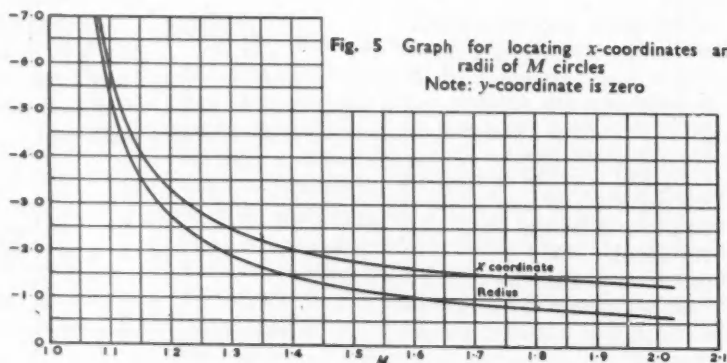
Fig. 5 Graph for locating x-coordinates and radii of M circles
Note: y-coordinate is zero
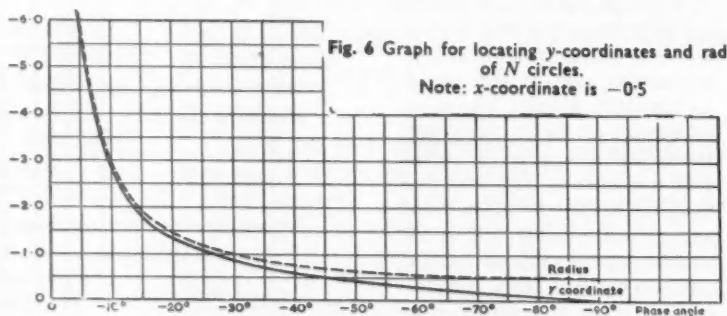
Fig. 6 Graph for locating y-coordinates and radii of N circles.
Note: x-coordinate is −0·5

PEOPLE IN CONTROL

by Staffman

BUTTERFIELD EVANS
sang-froid

Arthur Hillier, who retired as Chairman and MD of Sperry Gyroscope at the end of July, was with the company for 43 years, 21 of them as Chairman. I asked Sperry whether their MD, **Robert Broadbent,** would succeed Hillier as Chairman, but they were very cagey. However, it would appear to be a likely possibility. Broadbent joined Sperry as Works Manager in 1943, was appointed General Manager shortly after and became a Director in 1947.

BROADBENT
heir apparent

REEKIE
executor

They appear to have been tying up a few loose ends at Semiconductors Ltd., the transistor firm at Swindon, which is controlled by Plessey who own 51% of the company. The American Philco Corp. own the other 49%. An Executive Board has been formed consisting mainly of members of the existing Semiconductor senior management. **J. Reekie** is Executive Director and General Manager, **C. H. Noton** is Commercial Executive Director and **E. E. Webster,** who is Central Production Executive of Plessey's Swindon Group, is also an Executive Director of Semiconductors. The Executive Board is responsible to Plessey Director **A. E. Underwood** of the Swindon Group.

Hearing that Technograph Electronic Products, the printed circuit people, have appointed **L. C. Smith** Sales Manager, I asked him about the market for printed circuits in the control and instrument field. He said that ' the growing trend for electrical control and instrument manufacturers to use the newer and more advanced techniques is most noticeable.

They appreciate that the availability of printed resistors and inductors, and plated-through and double-sided printed circuits, means that their products can be more reliable, smaller and more economical to manufacture.' **P. Bartlett** has taken over from Smith as Technograph's Technical Sales Representative.

H. G. Stern, who has just been appointed to the Londex Board, tells me that there is an ever increasing demand for pressure, level and other automatic controls, and that, although it is an industry-wide demand, ' Londex are handling a gratifying proportion of this increased market.' He stressed the necessity for reliability, pointing out that this is becoming vital as systems grow more complex.

I was interested to learn that Wirepots have been acquired by the American concern General Controls and are trading under that name from a new factory in Basildon. General Controls is a large organization of 10 divisions and 50-odd sales offices in North America, and subsidiaries in Switzerland and Germany. The British company will continue under the present management, **R. Cramp** being in charge of Sales and **C. May** in charge of Production. Apart from the existing Wirepots range, they will manufacture single-turn precision rotary potentiometers, helical and rectilinear potentiometers and, at a later date, controls for industrial gas and oil heating, and solenoid valves.

The sufferer in my heading illustration is **L. J. Evans,** MD of Technicon Instruments Co. Ltd., British subsidiary of the American firm Technicon International. Evans was a volunteer patient at Guy's Hospital for an experiment, under Prof. **W. J. H. Butterfield,** which entailed the use of the Technicon 'Autoanalyzer' for continuously analysing and recording the blood sugar level from an artery and vein in his forearm. The idea was to measure the difference in blood sugar level between the arterial and venous streams after insulin had been injected into the

latter. A single Autoanalyzer was used initially, but this entailed passing arterial and venous flows through the instrument alternately. The experiment was repeated using two Autoanalyzers, and a 4½-hour record of blood sugar in the artery and the vein was obtained.

Technicon have appointed **A. G. J. Buckle** (ex-Chief Chemist of BICC's Helsby Division) Technical Director.

Mr. J. N. Toothill, a director of Ferranti, told me something of the problems of educating British industrialists in the potential savings to be made by fitting numerical control on machine tools. ' It is difficult to find anyone in British industry who understands,' he said, and he made the interesting point that the small firm with its directors in touch with the shop floor is usually more appreciative of the new techniques than the large firm—though it often has not the capital available to afford them. Toothill said that Ferranti have sunk £500,000 in their machine tool development in the last eight years. He added, ' There is not a chance of getting the money back '.

TOOTHILL
misunderstood

LEY
salesman

M. H. Ley, whom Westool Ltd., of St. Helen's Auckland have appointed Sales Manager, was Manager of ST & C's Rectifier Equipment Engineering Department, where he was responsible for both the design and sales of all rectifier equipment. Ley was with Ferranti prior to joining ST & C in 1939 and, apart from a two-year stint with Westinghouse Brake and Signal, remained with ST & C until he joined Westool.

IDEAS APPLIED . . .

. . . to Speed

A d.c. tachometer generator

E. M. DUNSTAN, Manchester University

In conventional d.c. tachometers a system of conductors is rotated in a d.c. magnetic field, and the e.m.f's induced in the conductors are synchronously rectified by a commutator and pick-off brushes. The output e.m.f. then has a d.c. component which can be made proportional to the speed of rotation.

Such devices can achieve a high degree of linearity in the speed range 50–3000 rev/min, but suffer from the disadvantage that a commutator ripple is generated which is of the order of 3% of the generator output, and whose frequency is proportional to the rotor speed. Such ripple can prove embarrassing unless it can be removed by suitable smoothing. At the lower speeds, however, the large time constant used for smoothing results in an increase of response time of the associated servo which is often undesirable. For example, if the speed of the output shaft of a reduction gearbox has to be servoed and the tachometer is coupled to the output shaft.

In the new tachometer the moving conductors are connected together at either end so that the e.m.f's generated cause currents to flow which in turn produce a d.c. magnetic field. (In particular the conductor system could consist of a hollow conducting cylinder.) This field can be made proportional to the speed of rotation and is measured by a sensitive magnetic field detector (second harmonic flux gate).

Operation

The principle of operation can be better understood by reference to Fig. 1, which shows a cylindrical conducting rotor placed in a magnetic field H_o. Rotation of the rotor in this primary magnetic field causes currents to flow in the rotor which produce a field with a component H at 90° to H_o.

Neglecting second order effects and assuming that the conductivity of the rotor material is constant, then:

$$H = k \omega \sigma H_o \qquad \dots (1)$$

where ω is the angular velocity of the rotor, σ is the conductivity of the rotor material and k is a constant relating to the geometry of the rotor.

In operation, the magnetic field set up by the rotor currents is balanced by that of a current in the feedback
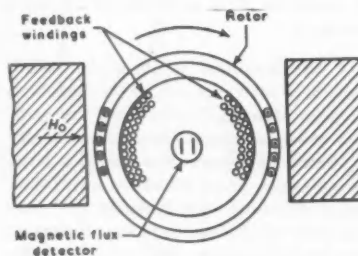
Fig. 1 The movement of the rotor produces a field at right-angles to H_o.

windings, arranged so that the current distribution is similar to that in the rotor. This current can be used as a direct indication of rotor speed.

The magnetic flux detector is used as a null indicator and, in conjunction with a suitable feedback system, maintains the equality of the two fields.

Sources of error

The use of the above technique leads to three main sources of error.

1. *Zero error*

This results from the presence of stray d.c. magnetic fields near the detector which will cause a current to flow in the feedback winding, to annul the stray fields, even when the cylinder is stationary. These may be due to:

a. Malorientation of the detector head with respect to the primary field H_o. Ideally, the head should pick up zero net leakage flux when properly positioned, but local heating of the detector caused by the modulation current distorts its geometry and can result in a net flux linkage.

b. Fields due to the proximity of magnetized objects, or in the limit the Earth's magnetic field.

This error can be reduced by careful design of the detector, magnetic screening in the vicinity of the head and by locating the head as far as practicable from the primary field H_o.

2. *Errors due to changes of conductivity of the rotor material resulting from changes of temperature.*

Such changes cause the constant of proportionality between H and ω in eq. (1) to alter.

The changes of temperature are of two types: changes of ambient temperature which cause a change of calibration of the tachometer, or, changes of rotor temperature relative to the ambient caused by the heating effect of the circulating currents. These introduce a linearity error which results in a smaller output than expected at higher speeds.

3. *Frequency effects in rotor bars*

Although the net result of rotor rotation is a d.c. magnetic field at 90° to H_o, the current in any one rotor bar varies over one revolution, the main frequency component being: f_r = rotor speed in rev/sec. The alternating nature of the rotor bar currents produces departures from linearity (decrease of output/rev/min) at high speeds due to:

a. The impedance of a rotor bar is not purely resistive, so that if the frequency of rotor currents becomes too high, the current and the field generated will be smaller than expected.

b. A second result of the complex impedance of the rotor circuit is a slight rotation of the d.c. field H in the direction of rotation so that the component of this field at 90° to H_o is reduced.

It should be noted that this 'skewing' of the d.c. field direction reverses with the direction of rotation of the rotor so that unless the field from the feedback windings is symmetrically disposed, the tachometer calibration will be a function of

Fig. 2 The physical layout of an experimental prototype constructed at Manchester University
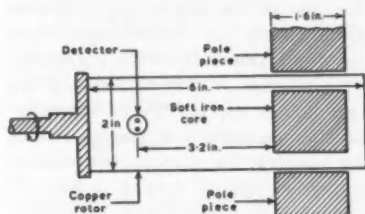
direction of rotation at the higher speeds.

Tests on the experimental tachometer have shown that this effect becomes important at speeds of the order of 100 rev/min.

c. The effective resistance of the rotor bars is a function of frequency due to eddy current effects.

As a general conclusion, to keep frequency effects small, the thickness of the rotor bars should be reduced to reduce eddy current losses, and the rotor diameter minimized to keep the inductance of the rotor assembly low. These requirements result in a reduction of generator output/rev/min, and therefore the value of stray field $\equiv 1$ rev/min, i.e., increases the value of the lowest measurable speed.

Fig. 3 The actual prototype
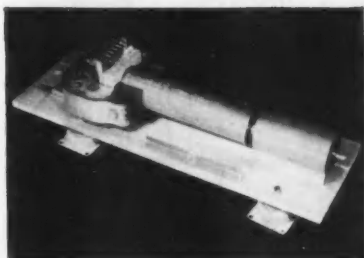
These three types of error form the boundary limits on the range of speeds which can be measured by the tachometer.

Experimental prototype

In an experimental prototype constructed at Manchester University, the zero error is better than 0·02 rev/min over a period of 8h, whilst the linearity error is less than 0·02% up to a speed of 100 rev/min where rotor heating and frequency effects begin to be important. These figures show that the device is capable of covering a wide speed range of linearity at speeds of the order of 100 rev/min or less.

Fig. 2 illustrates the physical layout of the experimental prototype and the complete device is shown in the photograph (Fig. 3). It can be seen that the detector is well removed from the primary field as suggested earlier. This necessitates a long slotted rotor to force the induced currents into the vicinity of the detector head.

Comparison with other tachometers

As was mentioned in the introduction, commutator ripple in conventional d.c. tachometers can prove embarrassing at low speeds due to the long time constant required for smoothing.

Methods of removing this time constant exist, which involve the addition of the amplified output of an accelerometer to the d.c. tachometer output before smoothing.[*]

Thus if the tachometer output is $v_t = k_1\omega$; and the amplified accelerometer output is $v_a = (Ak_2) . p\omega$

Then $\quad v_o = \dfrac{k_1\omega + Ak_2 p\omega}{(1 + pT_s)}$

where T_s is the smoothing time constant.

i.e. $\quad v_o = k_1\omega \dfrac{\left(1 + \dfrac{Ak_2p}{k_1}\right)}{1 + T_s p}$

i.e. when $T_s = Ak_2/k_1$ there is no effective lag introduced.

This method, however, is unsuitable for low speeds as the gain (A) involved becomes large and provision of adequate low frequency response in the amplifier results in noise due to rapid drifts.

In the brushless d.c. tachometer, commutator ripple is absent and the slot ripple very small, so that negligible smoothing should be necessary. This represent a considerable advantage over the commutator machine.

The tachometer can be adapted to measure low speeds in the range 0·01–

10 rev/min. This is made possible by increasing the thickness of the rotor and by modifying the primary magnetic field structure, to increase the rotor current per rev/min by a factor of 10. This means that speeds of 10 rev/min. can be measured to 0·02%.

It must be remembered that under these conditions, rotor heating sets the upper speed limit at approximately 10 rev/min.

This performance must be compared with that of a counter type tachometer. In this case a definite sampling time is necessary to ascertain the speed, as opposed to the continuous indication provided by the brushless tachometer. Being a digital device, the counter type machine can attain very high accuracies only, if either the sampling period is long enough or the count per revolution is large enough. For example, if the sampling period is 2 sec, a count of 15,000/rev is necessary in order to determine a speed of 10 rpm to an accuracy of 0·02%.

[*] West, J. C.: 'Tachometer noise reduction: the use of auxiliary accelerometer,' *Elec. Radio Engr.*, 1957, Vol 34, 9 (Sept), pp 342-4.

. . . to FLOW

Control valve for high pressures

Pressures and temperatures are being continually forced up in the development of new processes. To cater for this trend new valves are needed, and a recent example is Wee Willie (Fig. 4). This valve is suitable for working pressures of up to 50,000 lb/in.[2]. Originally designed in America some years ago, it is now being manufactured in the UK.

Fig. 4 The valve itself is on the right with the Domotor operator on top

The inlet pressure is directly connected to the valve seat ring which reduces the distortion in the valve body itself. The stroke of the valve is variable from a minimum of 0·010

in. to a maximum of 0·150 in., the operating force on the valve being 12,000 lb at the shortest setting and 2000 lb at the longest.

The force from the cylinder operator is amplified by the mechanism shown in Fig. 5. The gain is varied by moving the shoe along the run. Lost motion is eliminated by spring loading the operating parts (spring not shown in Fig. 5). The control valve is easily made reversible by turning over the shoe in its slide.

The hard valve stem is superfinished and passes through a special packing assembly which includes a combination Teflon '0' ring. Positive sealing is obtained at 30,000 lb/in² with a minimum friction factor. The input pressure rating is from vacuum to
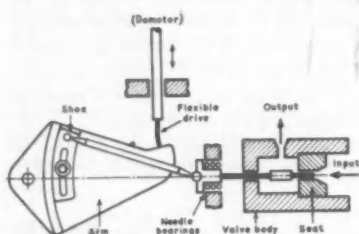

Fig. 5 A sketch of Wee Willie

50,000 lb/in² and the outlet from vacuum to 30,000 lb/in². With a normalizing fin the temperature range is from $-300°F$ to $+1200°F$.

The valve has a water C_v range of 0·000 000 1 to 0·1. The conventional open orifice valve seat and plug is not generally applicable to high pressure drop and flow rate, due to resultant high velocity, small area, lack of strength and limited rangeability. Each of the Flo-Mike valve seats is rated at a C_v rangeability of 1000 to 1 and by substitution of 1 of 2 Flo-Mike seat units a valve rangeability of 100,000 to 1 or 1,000,000 to 1 is obtained. By changing the stroke range to correspond with the desired maximum C_v, the same degree of plug positioning accuracy is obtained to assure precise flow control.

Wee Willie is further described in *New for Control* this month.

. . . to ANALYSIS

Automatic control of effluents

The detoxication and pH neutralization of cyanide and chromium bearing effluents may require up to an hour's reaction time in some systems.

This time has been greatly reduced in an automatic plant which has been recently exhibited by A. M. Lock & Co. Ltd.

The effluent passes through a reaction tank where an appropriate reagent, such as chlorine or sulphur dioxide, is added. The state of the reaction is monitored by an electrochemical detector. This, together with a controller, regulates the addition of reagent at a rate required to give complete detoxication without over-dosing.

Controllers are used to keep the pH of the effluent within the required limits (below 2·5 for chromium and above 10·5 for cyanide) for the appropriate treatment, and further pH controllers are used for the automatic neutralization of the effluent before it passes into the drains or rivers.

. . . to DENSITY

A useful recorder

There are not many pieces of equipment on the market which are suitable for recording the density of a continuously flowing stream of liquid. A recent one, which has come from the Continent, is the Pochan-Francel densimeter. It does not give a continuous reading of the density, but measures a batch automatically every few minutes, and records the value. This renders it impractical for use in processes with short time constants.

The construction and working of the densimeter can be seen from Fig. 6. The liquid to be measured passes through valve S_1 to the test tube E_1, in which the level is detected by the tubes N_1 and N_2, and the valve S_1 is closed when the level reaches an appropriate position. After a short stabilizing period the valve S_2 is opened and the liquid drains away. When the tube E_1 is empty the valve S_1 is re-opened, S_2 is closed, and a new cycle starts. The period of the cycle varies from 2–7 min.

The test fluid is compared to that of a reference liquid by a beam, from which floats are suspended. A chain is attached from one end of the beam to a fixed point. The difference in the densities of the two liquids is proportional to the sine of the beam's angular displacement from the horizontal. This relation is only accurate if the two liquids are exactly at the reference temperature. The maintenance of the liquids at the reference temperature is carried out by heating jackets T_1 and T_2. The heating fluid is between 10 and 20°C.

The cam R is designed so that the modulation of the pneumatic pressure, which actuates the recorder, is proportional to the difference in densities. When it is desired to measure large specific gravity differences weights can be added to the beam, which thus avoids changing the reference liquid or the chain counterweight.

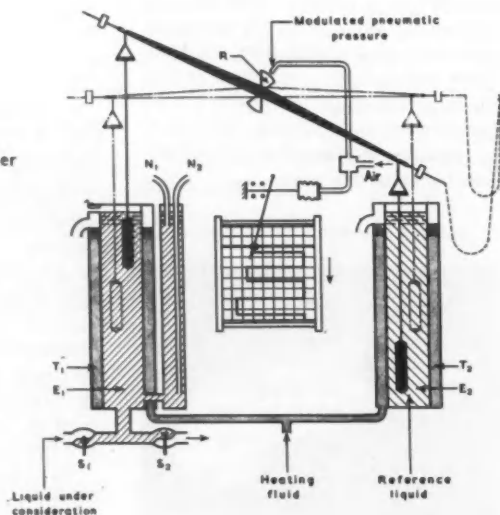The densimeter is supplied in the UK by Hunt and Mitton Ltd.

Fig. 6
The Pochan-Francel densimeter

. . . *to SERVOS*

An introduction to hydraulic servo valves—1

R. HADEKEL, Engineering Consultant, Sperry Gyroscope Co. Ltd.

This series of articles is addressed to engineers who are conversant with servo techniques in general, and who wish to acquire specialized information on hydraulic servo techniques. The first part deals with one of the keys to these techniques—the servo valve
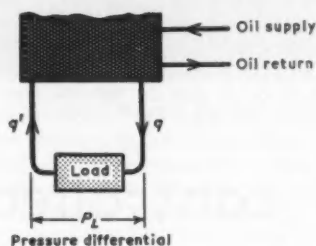
The servo valve as a black box

Fig. 1 The basic servo valve

Disregarding the input side, the valve provides a flow q to a load (jack or hydraulic motor). The return flow q' from the load is not necessarily equal to q, but this point may be disregarded for discussion purposes. Most valves are best regarded as sources of flow rather than of pressure, although in fact the two are interrelated.

The main input schemes
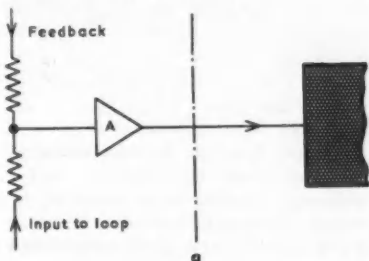
Fig. 2a An electrical input to a valve

Fig. 2b A mechanical input to a valve
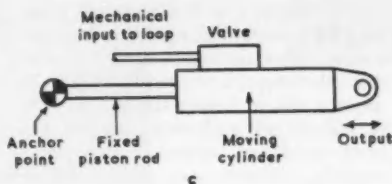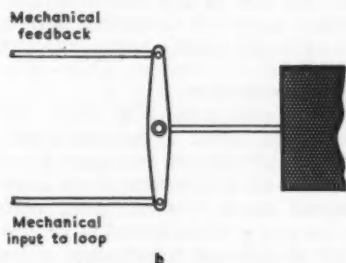
Fig. 2c A mechanical input with differential action inherent in the mounting
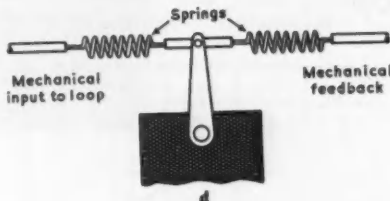
Fig. 2d Force differential input

Force devices (schemes 2d and 2e) depend on the fact that valve movement is small in relation to loop input and output movements. Scheme 2e is used in many process control actuators. Schemes 2b, c (more often c) are found particularly on power steering, aircraft flying controls, and copying machine tools. Scheme 2a represents the most flexible arrangement, and

Fig. 2e An electrical input and mechanical (force) feedback
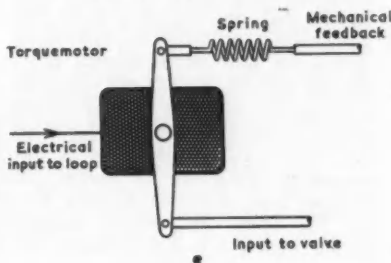
corresponds to the most usual general-purpose hydraulic servo valve, lending itself to any type of control loop (schemes 2b, c, d, are limited to position servos and to loop inputs presented in mechanical form; scheme 2e is limited to servos requiring position as an output).

In all cases, the input to the valve proper must eventually appear in mechanical form. The general-purpose electrohydraulic servo valve corresponding to scheme 2a may then be broken down as in Fig. 3.
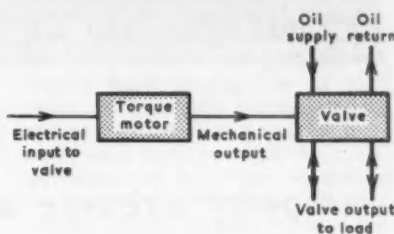
Fig. 3 The valve scheme 2a may be broken down to this

The rest of the articles will be devoted to valves of the above type. Commercial servo valves embody the valve proper and the torque motor in a single unit.

Torquemotors

Torquemotors for driving servo valves are transducers which transform an electrical input into a mechanical motion and force, and are therefore essentially similar to electrical meter or loudspeaker movements. Work output requirements are very much higher however, say up to about 1000 g-cm or more, depending on the type of valve. Frequency response requirements are far less than for loudspeakers, frequencies above 300 c/s seldom being of interest, while most valves have a useful range up to about 100 to 150 c/s. Due to the fact that the device works in a loop, high accuracy is seldom looked for (3% hysteresis and 10% or more non-linearity would not usually have any serious effect).

Power inputs vary widely according to the type of valve to be operated, and are typically 50-100 mW when
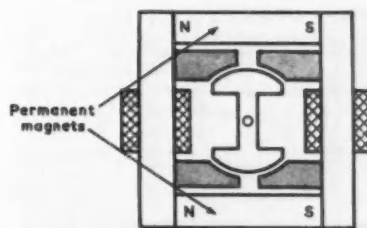
Fig. 4 A moving iron torquemotor

operating a first-stage flapper valve (see below), and of the order of 4 W when operating a slide valve. The present trend is to drive servo valves from transistor amplifiers.

Moving coil movements of the loudspeaker type are used, but the most popular kind of devices is of the moving iron type, a good example being shown in Fig. 4.

To be continued

Sperry airborne analogue computer closes air navigation loop
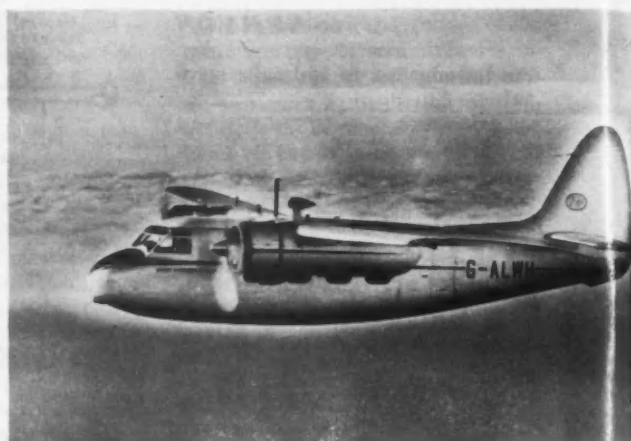
Fig. 1 Sperry's Percival Prince

Flight automatically controlled

ONE OF THE PROBLEMS FACING CIVIL air transport today is airspace saturation, a condition which undermines efficient aircraft operation by delaying take-off and by causing aircraft to fly at heights and along routes which are not ideal. Saturation occurs because it is necessary to separate adjacent aircraft by distances which are related to the accuracy with which they can be expected to maintain a pre-defined track. Improved tracking accuracies would, therefore, help to solve this problem.

Sperry Gyroscope have developed an airborne analogue computer known as the Radio Track Guide, which should improve tracking accuracies by

Fig. 2 Prototype Radio Track Guide during development stage. This is an airborne analogue computer which accepts and processes navigational information for display and/or flight control
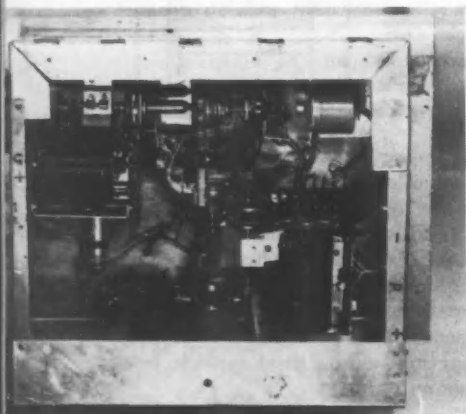
fully exploiting the positional information which is provided by existing ground radio aids. The system has been operated in the air, using Sperry's Percival Prince aircraft, in a five-legged flight along airways from London Airport to Le Bourget. Automatic tracking was carried out from the time that the aircraft reached operational height until Le Bourget was approached. Furthermore, the Radio Track Guide was coupled to the autopilot during part of the flight. This means that the aircraft's flight was completely automatically controlled, except for such minor manual pilotage as throttle adjustment. CONTROL understands that the Radio Track Guide is being further developed so that any manual adjustment is unnecessary. According to Sperry, no tracking error could be detected during the flight, this being checked against other aids including the marker beacon at Le Bourget.

Equi-spaced parallel tracks

The Radio Track Guide is capable of establishing a number of equi-spaced parallel tracks along existing airways and provides means by which an aircraft can lock on to them through its autopilot or accurately maintain them through a flight director. Tracks are established by the Radio Track Guide computer mounted in the aircraft. This accepts radio-navigational information, together with programmed data defining the required track, and presents to the pilot his lateral displacement from this track and the distance-to-go to its termination. Further versions of the computer

will accept a punched-card programme, thus permitting the navigational loop to be completely automatic. The only equipment required is the computer itself, and the new version of this will weigh about 50 lb and have a volume of 1 ft³.

The equipment can be used in conjunction with any aid which provides continuous and accurate fixes in two coordinates. The initial development work on the system has taken place in Europe using positional information provided by existing Decca chains. However, the basic concept is equally applicable to other ground radio aids such as Loran C, a type of navigation system now being considered; with Loran C it is estimated that by the use of 15 stations the entire USA area can be covered with positional accuracies better than 100 ft.

Apart from flight-testing, during which no tracking error could be detected, the system has been tested in a ground vehicle. A guidance path was defined on the ground down the centre of a mile long runway and the Radio Track Guide was used for guidance by a van carrying the apparatus. Sperry claim that the tracking error was less than 10 ft throughout and the vehicle came to a halt within this distance of the programmed destination.

Computer operation

The system is basically simple. Fig. 3 shows a system of equi-spaced rectangular coordinates, and points A and B which are the terminal points of the desired track. The computer illustrated in Fig. 4 is assumed to be at A and the position information is the

same as the demand information. Under these conditions the outputs from the two differential gearboxes are zero and the helical potentiometer wipers are in contact with the centre taps. The coordinates of position B are next demanded and result in outputs from the differentials which move the wipers away from the centre taps by distances proportional to the coordinate differences x_2-x_1 and y_2-y_1. The tracking meter is connected between the two wipers and at this point the voltages across the two helical potentiometers are adjusted to zero the meter. This setting-up procedure has defined the track and any subsequent meter reading will indicate a displacement from the straight line which passes through A and B. With this system, signal sensitivity and its sign are constant at all points along the track. An additional feature is that the track must pass precisely through B for at this point the wipers are again in contact with their centre taps. There is, therefore, no accumulation of errors along a typical route which would be formed by a succession of such tracks.

By using a zeroing procedure at the start of a track it is possible to reduce the number of components in the system requiring a high degree of accuracy. The only accuracies required are in relation to backlash in the gears and the linearity of the helical potentiometers. Potentiometer loading effects are eliminated by using a voltage balance system. Moreover, supply variations will not affect the accuracy of the defined track.

The distance-to-go facility is not indicated in Fig. 4. Since the accuracy of this information is not critical it may be derived from strip potentiometers mounted adjacent to the helical units.

Some problems

This simplified description of the computer needs qualifying on certain points. For example, it would be inappropriate to require an aircraft to remain poised at point A while establishing a track to B. As the track is to pass through A, it is not sufficient, to allow setting-up to take place in the region of A. However, for operational purposes this is the type of operation required and by a simple trick it is accomplished. The trick is really on the computer, for on closing A the setting-up procedure is initiated and begins by falsifying the navigational information so that the computer believes it is stationary at A. When the track is established, the false information is removed and normal tracking is recommenced.

The operation of the computer has

been described within a system of rectangular equi-spaced coordinates, and this is just the coordinate system which is not produced by a hyperbolic aid. The tracks established by the computer will not, therefore, be straight in space but a method has been developed which can produce straight tracks from hyperbolic information. This method, in effect, introduces correcting voltages across the two helical potentiometers and thereby retains the basic feature of the system which ensures that the track passes precisely through the defined terminations.
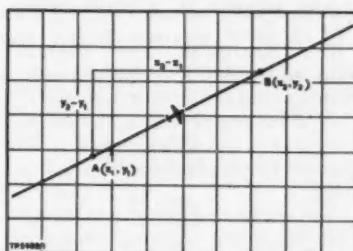

Fig. 3 A system of equi-spaced rectangular coordinates. A and B are the terminal points of the desired track, the aircraft being at A

Punched-card operation

Computer operation can be automatic. The route data is contained on a punched card which holds sufficient data to define 20 successive tracks. Much of this data is required to define the terminations of each track. To maintain system accuracy it is necessary to define termination points to an accuracy similar to that available from the navigational system being used. In the case of Decca, this requires an accuracy of 1 in 30,000; thus, it has been necessary to develop a miniature digital servo capable of handling 15 binary digits.

It is not necessary to use track shaping and automatic data insertion in computers for all applications. A

Fig. 4 The computer-controlled aircraft is at A in Fig. 3 so that present and desired position are the same. To give the required track, A to B, the wipers move from the centre taps by distances proportional to x_2-x_1 and y_2-y_1
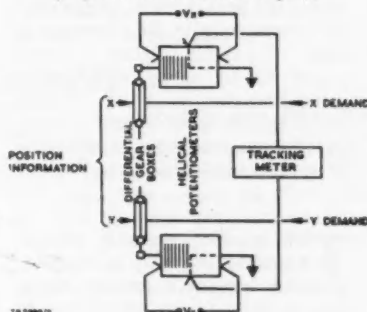
system for use with Dectra, a hyperbolic aid providing guidance across the North Atlantic, will probably not require track shaping, for at long range the hyperbolæ become straight and equi-spaced. Also the use of automatic data insertion would be a disadvantage. On this route, no precise air lanes are specified because flexible routing permits aircraft to take full advantage of the prevailing weather. Thus for this application the Radio Track Guide would permit the manual presetting of data. This data would be provided by the relevant control authority and would be based on weather conditions and other aircraft movements and liable to changes at any time while in flight.

An automatic computer without track shaping will probably satisfy the needs of helicopter operation. Here the requirement is for maximum accuracy along a number of short tracks which may well be required to terminate at the desired landing spot.

Autocontrol in time and space

Sperry feel that considerable development of the Radio Track Guide appears possible in integrating the device into an air traffic control system. For example, by the selection of suitable coordinates, any reporting point within an airway could be offset from the airway centre-line so as to avoid 'funnelling.' With such a system it would be possible automatically to control aircraft in both time and space and thereby fully utilize the airspace available. This would require a ground computer for the production of route programmes and for checking flight clearances. Data produced by the computer would be stored and used subsequently to check the progress of aircraft during their actual flight.

Obviously such a scheme is a long way off but, to Sperry Gyroscope, its development appears to follow a logical sequence which could proceed at a rate such that it is always one step ahead of air traffic control requirements.

Conclusions

The Sperry Radio Track Guide is suitable for military and civil aeroplanes including helicopters. An airborne analogue computer, it provides a coupler system for the instrument and automatic flying of radio pattern networks such as Loran, Decca, Dectra, Vortac and Gee. It follows that the system should provide improved all-weather aircraft operation. The punched-card flight planning facility has obvious application to air traffic control. It may provide increased safety in the airways and allow greater traffic density.

Pick-off *by 'UNCONTROLLED'*

WHEN some members of the Control Section of the SIT recently visited the Coryton refinery of the Mobil Oil Co. I was glad to be one of the party, not only for the technical interest of the refinery instrumentation but also because I had never previously seen that tongue of land on the north bank of the Thames which now houses Shellhaven, Thameshaven and Coryton oil refineries and storage depots. Glimpses of these from the road approach — silver-grey in the evening sunshine — made me appreciate that refineries are not wholly lacking in beauty and intractable to architectural treatment. Coryton works are certainly very well laid out and it was refreshing to see that Mobil are starting to use the kind of open-air colour coding of pipes and valves which the UKAEA delights in.

The refinery is probably as advanced as any in this country in its use of on-stream analysers. These include an automatic gas-liquid chromatograph on the depropanizer column of the liquefied petroleum gases unit, a gasoline vapour pressure analyser on the distillation unit, and three paramagnetic oxygen analysers on the main power station boilers. All these are said to have paid for themselves in 3-12 months.

Indeed, the SIT party chose an opportune day for analysis since two new instruments had arrived the same morning and were only just unpacked: a gas calorimeter from Germany and an H_2S analyser from the USA. These are to be fitted on a new plant being constructed at the refinery, a gas purification unit to supply refinery tail gases for treatment by the North Thames Gas Board. In all this unit will have four on-stream analysers; but none of them is to be used for feedback control—that still lies in the future.

I WONDER whether the following note which I have received from a correspondent has its practical uses:

'Seventy-five years ago this June *Engineering* announced that " Mr. George Westinghouse Jun., of Canal Road, King's Cross, London, has brought out an electric governor in which a solenoid, traversed by the electric current, controls the distribution of fluid under pressure to a small cylinder. . . . "

'The description and diagram showed the piston of the hydraulic cylinder linked to the steam regulator of the engine side of the set. In short, here was servo control of an engine-driven generator on variable load.

'The reference element was an adjustable spring opposing the travel of the solenoid armature. The armature controlled the admission of fluid by means of a dumb-bell valve. The pressurized fluid was introduced opposite the neck of the piston, leaving it in equilibrium '.

Does anyone know of an earlier example of an electrohydraulic servo ?

ELSEWHERE in this issue appears a note on the new Ferranti machine tool control equipment. Recently I talked to Mr. D. T. N. Williamson, the Head of Ferranti's Machine Tool Control Department, about the hydraulic servos now used as standard in the continuous path equipment. He told me they were designed by the engineers in his department without importing any hydraulics specialist from the aircraft or guided-weapon industry. 'We are no longer " electrical engineers " here ', he said, ' we are " engineers " '. That is fine and represents an encouraging, if unusual, outlook. But should he not really have said, ' We are " control engineers " or " engineers with the systems outlook " ' ? I doubt whether his team would be so happy designing a turboalternator or a new bridge across the Clyde. It is work on control systems that provides the elixir of the anti-specialist engineer today.

THE phrase ' scientific breakthrough ' is much in fashion, probably because a military metaphor appeals to the emotions. It was much, and mistakenly, used during the recent flurry about electrochemical ' fuel ' cells. The stir centred around a demonstration of Bacon's hydrogen - oxygen cell, which is being developed by Marshall of Cambridge for the NRDC. My impression at the demonstration was that there had been a good deal of slogging development rather than a sudden revelation. After all, electrochemical cells 'fuelled' from outside (instead of carrying their entire chemical stock within themselves) were thought of over a century ago, and Bacon himself has been working steadily on the project for twenty years. Cells using hydrocarbon fuel are being developed at the Sondes Place Research Institute, and work is also known to be under way in the US, Germany and Holland.

Two main problems that now seem to have been mastered at Cambridge are the control of the gas pressures and the control of the quality of the electrodes. The electrodes themselves are disks of porous sintered nickel, and 40% sodium hydroxide solution is contained between them. Surface tension prevents the compressed gases (300-600 lb/in²) from bubbling through the electrodes into the electrolyte. To protect the cells, the pressures of the gases on the two sides have to be equalized, and the Cambridge team has very sensibly relied on off-the-shelf equipment for this control: The work is concerned with the unknowns of fuel cells, not the development of pressure regulators.

The forty-cell unit at Cambridge generates 2½ kW at 32V, or 5 kW at 24V maximum load. The unit has a rated free-energy efficiency of 50%, but the heat evolved is not wasted; the temperature must be kept at 200°C for the catalytic reaction to go. Applications are foreseen, given suitably developed control systems, to heavy traction, air- and space-craft, and (with auxiliary electrolysers) to the storage of the off-peak output of nuclear power stations.

Polarography and its Industrial applications

We regret that some printing errors appeared in the article by D. G. Anderson last month. The section heading *Increasing the total ion concentration* on p. 82 should have come after the explanation concerning the two reductions of iron, not before. Reference 4 should have read ' Delahay, P., and Adams, T. J., J. Amer. Chem. Soc., 74, 1952, p. 5740.' Reference 5 should have named ' G. C. Barker,' not ' Barkor.'

118

New for Control

ELECTRIC RELAY

small, low capacitance

A miniature low capacitance G.P. relay has been produced by Ericsson Telephones Ltd.

It is intended for use in circuits requiring a small 2 changeover relay with low capacitance between springs, and between springs and frame. The conventional flat springs have been replaced by wire springs mounted in moulded blocks.

Typical performance characteristics at 1000 c/s give a capacitance of not worse than 1 $\mu\mu$F between all springs and not worse than 2 $\mu\mu$F between springs and frame.

Tick **No 187** on reply card

COOLING FLUID

for very high temperatures

A cooling fluid for use in computers, control systems, and other types of electronic equipment has been developed by Monsanto Chemicals Ltd.

The fluid, Montosil E, has been specifically developed for use in electronic systems capable of withstanding very high temperatures. Montosil E has excellent dielectric and thermal properties and good lubricating and hydraulic characteristics. The fluid has adequate viscosity throughout the temperature range between −65°F and 400°F, and its pour point is below −100°F.

Tick **No 188** on reply card

TEMPERATURE CONTROLLER

with an accuracy of 0·025%

The Winston-United Steels temperature controller (type M.226) is claimed by the manufacturers to be able to control to an accuracy of 0·025% at 1000°C. The instrument was designed to operate furnaces used in creep testing alloy steels.

A platinum resistance thermometer is formed into an a.c. Wheatstone bridge, the pre-set arm of which consists of a 1000 ohm potentiometer graded in 4000 steps, each being 0·25°C. The out-of-balance voltage from the bridge is amplified by a two-stage amplifier giving a gain of approximately 2000. The amplified output is also fed to a phase-sensitive bridge, which gives a positive or negative output according to whether the furnace temperature is lower or higher than the correct setting. This output is amplified 10 times by the d.c. amplifier

and then applied to one section of the relay controlling the furnace relay. A time interval generator provides switching cycles of, normally, 30 sec to the other section of the relay control, which is so connected that the first section conducts, thus energizing the relay only when the control signal from the thermometer is more positive than the signal from the time interval generator. When the fur-
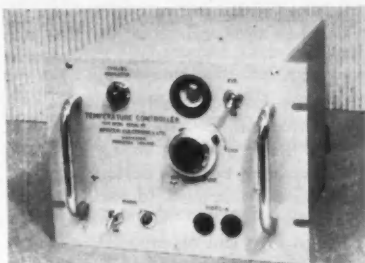
A rugged, accurate controller

nace is at the correct temperature, the relay is energized for one half of the time cycle. The switching of the furnace relay is used to alter the furnace current between two valves chosen to match the furnace characteristics.

The controller is manufactured by Winston Electronics Ltd.

Tick **No 189** on reply card

SWITCH

an unusual controller

An interesting switch from Pye which should find many applications is the joystick multi-circuit controller. The controller consists of a joystick which can be moved in any one of two, three, or four directions to make or break a number of circuits; the controller being of the lock-on or spring return to centre type. A great saving in panel space can be made by using the switches, e.g. a four-way eight position unit can save eight push-button assemblies. Replacement of the individual microswitches is simple.

Tick **No 190** on reply card

COUNTERS

batch and impulse

A new type of multi-circuit batch counter is being marketed by Radiatron in their IVO range. This counter has 2 or 4 preset count positions. The instruments are available to count either shaft rotation, electrical impulses or strokes (oscillatory movements). The counters change over

two or four independent electrical contacts when the respective numbers are reached, and the whole cycle is repeated on depressing a zero set lever or turning a detachable key. Electrical reset is also available. The single and the double counters are available up to 6 digits and the quadruple counters up to 3 digits. In each case the numbers corresponding to the various circuits are adjusted independently of one another with finger-grip wheels.

A small electrical impulse counter, also an IVO range product, is suitable for counting up to 20 impulses per second. The counter is made for both d.c. and a.c. pulses, the minimum pulse length being 25 msec for d.c. and 33 msec for a.c. The counter is available in non-reset type or with an instantaneous resetting knob or with a reset key.

Tick **No 191** on reply card

NANOSCOPE

for fast repetitive waveforms

The Nanoscope is an auxiliary unit which, when connected with an ordinary laboratory oscilloscope, permits the observation of very fast repetitive waveforms of the order of a few nanoseconds (10^{-9} sec) duration. It has been developed by the AERE, primarily for use with scintillation counters.

It operates by sampling the fast waveform with very narrow pulses at a number of points. This results in the production of a series of pulses, stretched to

The Nanoscope

render them visible on a normal oscilloscope of restricted bandwidth, which are proportional in amplitude to the corresponding ordinates of the sampled waveform. These ordinate pulses are brightened at their peaks, thus tracing the fast waveform as a series of dots on the oscilloscope.

Most laboratory oscilloscopes are suitable for connexion to the Nanoscope,

which requires connexions to the time-base and to the cathode of the tube. In other cases these connexions can be made very simply by the user.

The Nanoscope costs £350 and is manufactured by Lion Electronic Developments Ltd.

Tick **No 192** on reply card

CONTROL RELAY

operated by less than 5 mW

A new control relay (type 213B) has an operating power of less than 5 mW, with which it can switch a maximum of 15 A at 230 V a.c. (non-inductive). The unit uses a transistor relay and is designed for the remote switching of loads where the power through the control contacts must be kept to a minimum. It provides its own control current and thus cannot be operated by external signals.

The manufacturers are Electromethods Ltd., the price is £9 10s. and delivery can usually be made in 2 weeks.

Tick **No 193** on reply card

ANALYTICAL INSTRUMENT

automatic, continuous

A new Technicon Autoanalyzer system for continuous automatic analysis of chromatographic fractions is announced by Technicon Instruments.

Operating as a separate analytic entity in the chromatographic set-up, the Autoanalyzer can accurately handle either the full-stream delivery of the column effluent, or any part thereof. Thus a column yield can be split two ways at exit, with a part flowing directly into the Autoanalyzer and the rest into a conventional fraction collector for preparative work.

The combined outputs of any number of columns and fraction collectors can be continuously analysed at a rate of up to 60 samples per hour. The self-cleans-

ing system is applicable to such diverse materials as amino acids, proteins, peptides, polypeptides, steroids, phosphates and many others.

Modular design permits full flexibility of arrangements: building blocks can be purchased as required. The basic system includes proportioning pump, mixing coil, heating bath, colorimeter and recorder. A programming mechanism is available accurately to effect the correctly timed sequence of a series of changes.

Tick **No 194** on reply card

TRANSISTOR TEST SET

fully automatic, flexible

An automatic test and data recording machine for the testing of transistor devices has been produced by Sylvania-Thorn Colour Television Laboratories Ltd.

The machine can apply up to ten tests per device with a maximum resolution of ± 2%. Basic rate of testing is 10,000 tests per hour, i.e. 1000 devices per hour, with ten tests applied to each. The results are recorded simultaneously on punched tape and on printed pages. The tests are applied sequentially, and the machine is able to compare readings with prescribed upper and lower limits for every test. Whether the readings on any single device under test fall inside or outside the prescribed limits can determine whether some or all of the remaining tests are applied or inhibited. The present ranges of current voltages are 1 μA to 10 A and 100 mV to 1 kV.

The equipment is fully transistorized and uses standard telegraph machinery for producing output data. All analogue quantities which are generated during the tests procedure are digitized, first into a five-bit straight binary code for processing by the machine, and subsequently

into the International Telegraph Code for output purposes.

Tick **No 195** on reply card

PNEUMATIC RELAY

gives automatic compensation

The size of an orifice plate for measurement of gas flow is calculated for one temperature and one pressure; it follows that any variation in either will affect the accuracy of the final reading. In most cases variations are small and the effect on metering accuracy is negligible. However, instances do arise in which large changes in either pressure or temperature, or both, are encountered and it is then necessary to apply a correction. Honeywell Controls Ltd. are
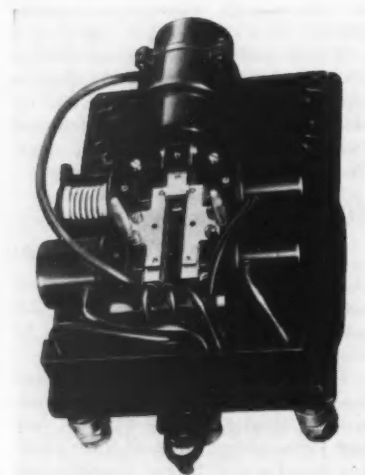
The Sorteberg pneumatic relay

now able to supply a system providing automatic compensation for either temperature or pressure, or both—using the Sorteberg force bridge pneumatic relay. This is essentially a multiplying and dividing unit which corrects the flow signal for pressure and temperature changes.

The pressure and temperature transmitters are calibrated from absolute zero to the maximum values for which compensation is required expressed in absolute units. Transmission is such that zero absolute is 3 lb/in² whilst the maximum reading gives 15 lb/in². The flow transmitter is a standard differential converter, or similar transmitter, which does not incorporate square root extraction.

Tick **No 196** on reply card

PLOTTING TABLE

accuracy of 0·1%

The Bryans X-Y coordinate plotting table is a self-contained instrument for bench or desk use. The plotting area is 15 × 10 in. and the maximum pen velo-

The set-up for the Technicon Autoanalyzer

city is 20 in./sec. The full excursion on the Y-axis of 10 in. peak-to-peak may be obtained up to frequencies of 0·75 c/s.

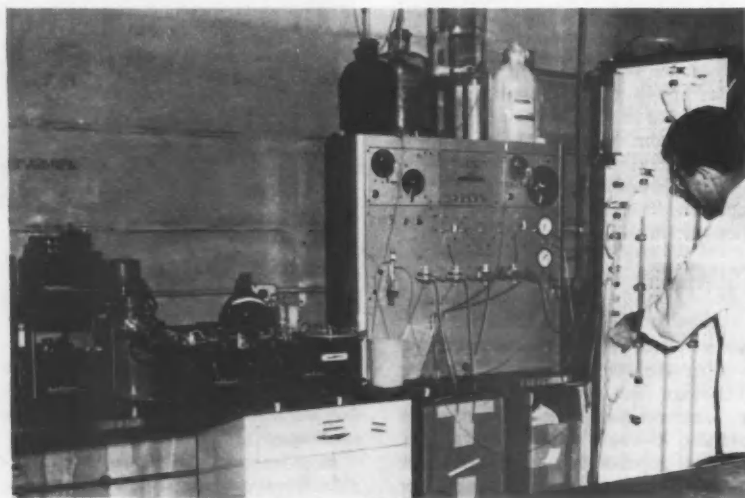For amplitudes within the limitations of maximum pen velocity, the pen response is such that the amplitude is reduced to 70% of the d.c. value (i.e. 3 dB down) at 5 c/s.

The sensitivity or scale factor of each axis is variable over a range of 0·08 to 8·0 V/in. by coarse and fine controls. The plotting accuracy is about 0·1% of full scale. The dimensions are 24 × 20 × 8 in. and the weight is 65 lb.

Tick **No 197** on reply card

CONTROL VALVE

pressures up to 50,000 lb/in²

The Wee Willie control valve (model 5060) has been designed for a working pressure of 50,000 lb/in².

The standard body is of stainless steel (type 316) forged to specification FN-58J in an angle pattern only. All forgeable alloys are available on request. The temperature rating for a standard body is − 20 to + 400°F, but with a normalizing fin this becomes − 300 to + 1200°F.

The plugs are available in 3 C_v ranges 0·000 000 1 to 0·001; 0·000 001 to 0·001; and 0·0001 to 0·01. The packing is by a Teflon 'O' ring. Standard connectors are ¼ in. NPT or BSP.

The standard operator is a Domotor with integral positioner. The valve stroke is adjustable from 0·010 to 0·150 in. from the closed position. The valve can be fitted to fail open or closed, and it is reversible without change of parts.

Wee Willie is made by the Audley Engineering Co. Ltd.

Tick **No 198** on reply card

X-Y RECORDER

accuracy better than 0·75%

The HR-92 X-Y recorder is a null-balance servo-type plotter designed to draw curves in Cartesian coordinates with an accuracy of better than 0·75%.

Sensitive, well-designed

The flat-bed bench mounting construction utilizes 8½ × 11 in. graph paper with full chart visibility. The X- and Y-axes are electrically and mechanically independent; each employs a chopper-type amplifier with separate power supply, a two-phase servomotor and a 3-turn rebalance potentiometer energized by a mercury reference cell. The response is critically damped, with a pen speed of 7·5 in./sec and sensitivity of 10 mV/in. (alternatively 1 mV/in.) The input resistance is 10,000 ohms but can be adjusted by removing an internal link to give an infinite impedance at balance. The simplified control panel has duplicate zero setting and continuously-variable attenuator adjustments, separate standby and power switches, and a 'load-operate' control which removes the pen carriage to facilitate rapid chart loading. Gain and calibration adjustments can be made by screw-driver controls readily accessible beneath the front panel. The overall dimensions of the recorder are 14 × 15½ × 8 in. and the weight is 35 lb.

The agency for Houston equipment in this country has been acquired by Scientific Furnishings Ltd.

Tick **No 199** on reply card

DETECTOR

for liquid gases

A sensing unit that detects the presence or absence of liquid gases or cryogenic fuels in a transfer line or vessel is being marketed by the American associates of Honeywell Controls Ltd. The detector is a three-part control unit consisting of a probe, amplifier and connecting coaxial cable. The probe consists of a series of Teflon-spaced stainless steel concentric cylinders. When the probe is inserted in a vessel or transfer line, the presence or absence of a liquid results in a change in capacitance as the liquid fills the space between the cylinders. This measured change is transmitted by coaxial cable through an explosion-proof flexible conduit to a transistorized amplifier where it is converted to energize a double-pole double-throw relay.

Tick **No 200** on reply card
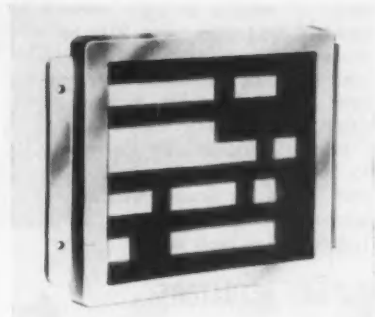
INDICATOR BLOCK

a different approach

A 99 dot electroluminescent indicator block now being manufactured by Thorn Electrical Industries Ltd. applies a new principle to digital read-out and progress chart systems.

This component has a depth of only 0·3 in. and occupies a fraction of the space used by lamp indicators. No filaments are employed, the unit generating virtually no heat at all. The component consists of 99 rectangular phosphor dots sandwiched between two electrically con-

ducting surfaces. By applying alternating voltage to these dots they are excited to luminescence. Variation in the pattern of illuminated dots enables the indicator to read out any desired character or figure or to provide an accurate reading of progress.

The brightness rating of the indicator is 15 lamberts. To develop the intensity

An example of one of the new indicator blocks

required it is desirable to use a high frequency supply of a voltage of about 350 V. Thorn transistorized power packs are available producing such a supply on 400 c/s, the voltage being low enough in this instance to avoid difficulties in switching.

Tick **No 201** on reply card

VOLTMETERS

3 and 4 digit models

Three and four digit electronic voltmeters have been produced by Blackburn Electronics Ltd. The accuracy is ± 0·1% on the 3-digit BIE 2113 and ± 0·05% on the 4-digit BIE 2114, on any of the four ranges of each voltmeter. The input impedance of both instruments is 50 megohms in the lower range and 5 megohms in the upper ranges. Range changing and sign selection are automatic and both are indicated on the visual display which employs neon number tubes. The readout times of the instruments are 13 millisec for the BIE 2113, and 103 millisec for the BIE 2114.

Both instruments have built-in stabilized power supplies and can be supplied either for rack mounting or in an instrument case measuring 20 × 14 × 17 in. The prices of the instruments are BIE 2113 £450, and BIE 2114 £500.

Tick **No 202** on reply card

AUTOMATIC WEIGHING EQUIPMENT

for heavy industrial use

Equipment for automatic weight control has been developed by Elcontrol Ltd. It involves the use of one, two or three load cells on which the load is supported. The load may alternatively be

suspended from up to three suspension type load cells. The load cells are connected to a remote relay unit which integrates the output from the cells. The integrated output current is monitored and when it reaches a value corresponding to the selected operating weight, the relay in the control unit is operated and actuates the control mechanism.

The equipment is suitable for the range of weights normally covered by standard load cells, from 50 lb up to a thousand tons or more, and is provided with operating adjustment over any desired range of weights. It gives repetitive accuracy of better than 1%.
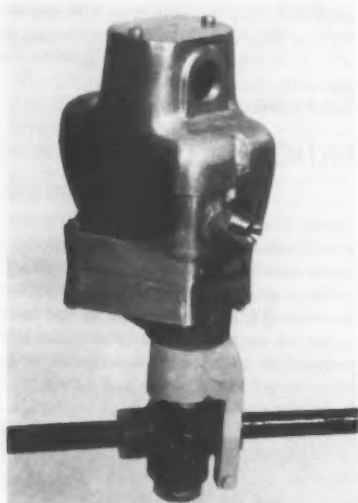
Price of a typical unit for weights up to 2000 lb employing one load cell, is £120. Units for greater weights and in heavier housings cost more.
Tick **No 203** on reply card

ROTARY ACTUATORS
angular travel of 90°

An electropneumatic rotary actuator from Kinetrol has a torque of 150 lb-in. and an angular travel of 90°. It is based on a single rotary-vane piston design and

The electropneumatic actuator

works from an air supply of 80–100 lb/in². The valve can be supplied to work from an electrical input of 230 V a.c., 12 V d.c. or 24 V d.c. The overall dimensions are 3·9 × 4 × 5·5 in.
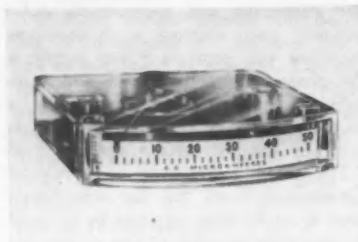Tick **No 204** on reply card

QUICK LOOKS

A new range of solenoid-operated pilot valves has been developed by Maxam Power Ltd. The solenoid is designed around a 24 h water immersion tested coil of low current consumption (4–8·5 W). The valve has only two moving parts. The maximum operating pressure

for a $\frac{1}{16}$ in. orifice, 2-way normally closed valve is 250 lb/in² gauge.
Tick **No 205** on reply card

A miniature edgewise meter (model 220) has been produced by Taylor Electrical Instruments Ltd. The instrument can be supplied as a voltmeter, milliammeter or microammeter.
Tick **No 206** on reply card

A new photomultiplier tube (type 9558B), which has a tri-alkali photocathode formed from antimony sodium potassium caesium, has been introduced by EMI Electronics Ltd.
Tick **No 207** on reply card

Counting Instruments Ltd. have informed us that they have been developing a compact binary-decimal converter. Known as the Bina-dec it has been designed for use with their 1 in. or $\frac{5}{8}$ in. digital display units.
Tick **No 208** on reply card

Five new miniature transistor transformers have been added to the Microtran Company line. These units are available in open frame construction with standard channel or plug-in tab mounting channel. Their size is less than $\frac{1}{2}$ in³, with a weight of approximately 4/10 oz. Impedance ranges were designed to meet the requirements of many new transistors.
Tick **No 209** on reply card

The all-welded construction of a new miniature relay from International General Electric is claimed to have reduced contact contamination—an obstacle in achieving relay reliability. Rated at 2 A 26·5 V d.c. or 115 V a.c. the relay works from d.c. and weighs about 1 oz.
Tick **No 210** on reply card

A recent addition to the range of 'oil free' air compressors manufactured by Williams and James (Engineers) Ltd. is a 2-stage double-acting water cooled model for pressures up to 250 lb/in², whilst delivering up to 55 ft³/min of free air. It is noticeably silent in operation.
Tick **No 211** on reply card

A wide range frequency meter (type TD/1) from Telemechanics Ltd. will be available early next year. The measuring range is 0–3000 Mc/s as a generator, and 1 kc/s–3000 Mc/s as a meter; with a measuring accuracy of ± 1 cycle. The generator output voltage is 0·1 volt.
Tick **No 212** on reply card

INDUSTRIAL PUBLICATIONS

Colourful leaflet from Bendix describes the G-15 general purpose **digital computer.**
Tick **No 213** on reply card

4-page Solartron bulletin contains special features and specification sheet for magnetic tape **recorder-reproducer system.**
Tick **No 214** on reply card

1959 catalogue of books on electrical and electronic engineering—H. K. Lewis & Co. Ltd.
Tick **No 215** on reply card

Hewlett-Packard news sheet details information of a clip-on **oscilloscope probe** for measuring and viewing current waveforms.
Tick **No 216** on reply card

Useful CIBA(ARL) booklet entitled 'How to use Araldite Epoxy Resin Adhesives'—a guide to materials which can be bonded by **Araldite.**
Tick **No 217** on reply card

Technical and installation data sheet of Drallim Industries **fine control valves.**
Tick **No 218** on reply card

A well-compiled catalogue of **pneumatic** equipment from Air Automation.
Tick **No 219** on reply card

Two glossy, fully illustrated brochures on Hilger & Watts' **autocollimators** and recording infra-red **spectrophotometer** (H800).
Tick **No 220** on reply card

NGN Electrical Ltd—ring folder contains data sheets of **high vacuum** equipment which includes pumps, components, plants etc.
Tick **No 221** on reply card

First issue of quarterly publication by Institution of Mechanical Engineers entitled 'The Journal of Mechanical Engineering Science.'
Tick **No 222** on reply card

Leaflet and price list of Elkay Electrical Manufacturing Co. Ltd. range of **connectors** and **terminal strips.**
Tick **No 223** on reply card

Evershed & Vignoles 10-page publication on **f.h.p. motors**; ratings range from 0·25-100 W output.
Tick **No 224** on reply card

4-page leaflet from George A. Philbrick Researches Inc. gives brief details of their various **analogue computing instruments.**
Tick **No 225** on reply card

Informative catalogue on Dixylon plastic **transmission belting**—R. & J. Dick Ltd.
Tick **No 226** on reply card

For further information on any industrial publication tick the corresponding number on the prepaid reply card
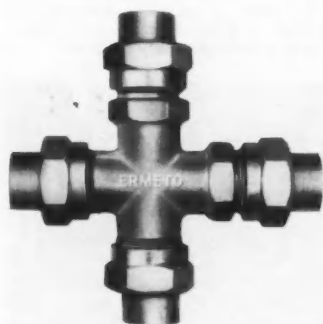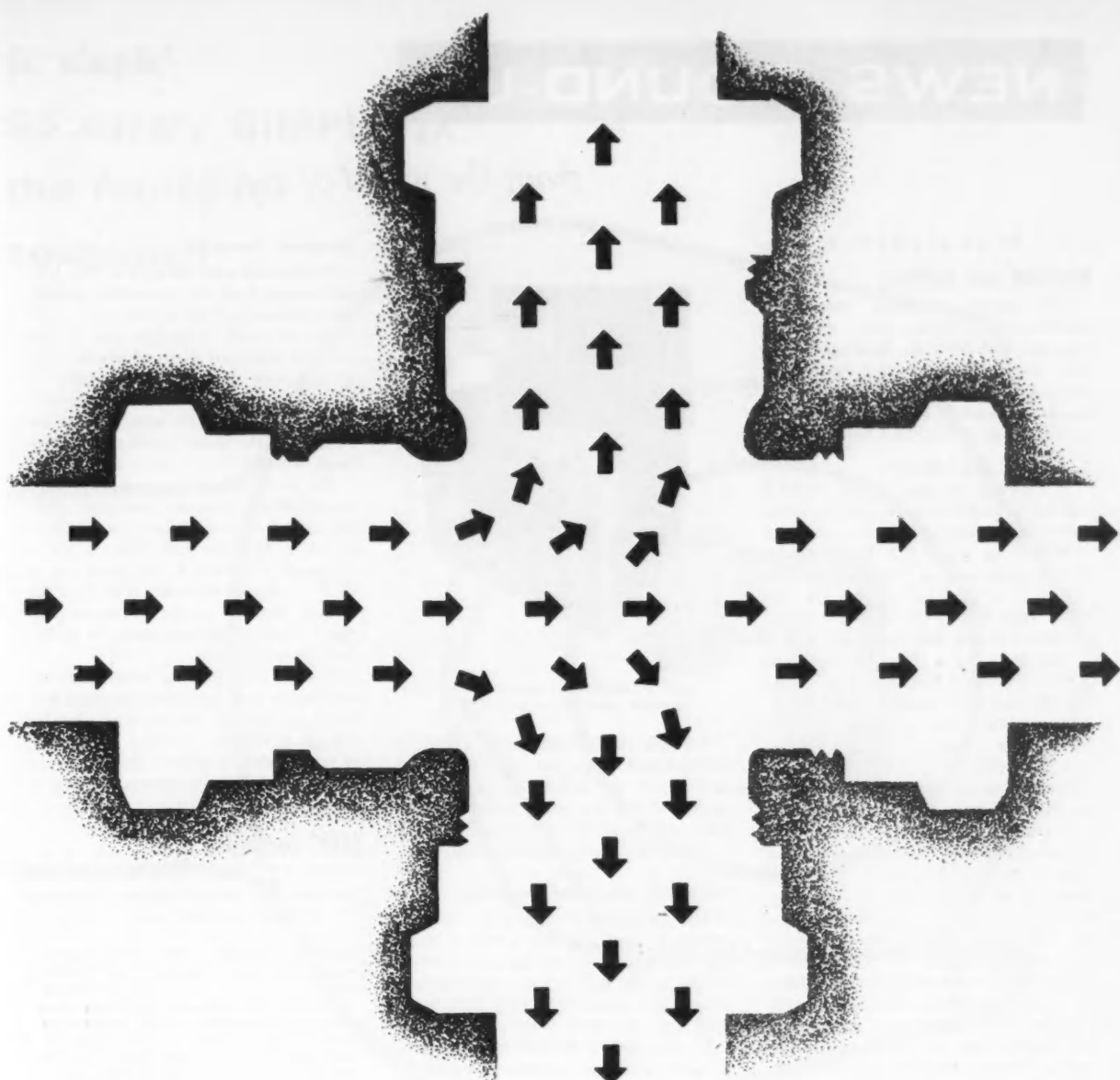
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—— MACHINING ——

Machine tool controls

Last month Ferranti, Edinburgh, demonstrated three new electronic machine tool controls. Developed from their earlier machine tool equipment, they are for continuous path control, numerical position control, and automatic inspection of machined parts.

Continuous path control

A drawback of the current Ferranti continuous path control equipment is the short playing time of each magnetic tape—20 min for an 1800 ft tape—dictated by a playing speed of 15 in./sec to avoid too high a packing density for the pulses recorded on the tape. This speed is reduced in the new equipment to 3·75 in./sec by using a phase displacement carrier system of pulses at a frequency of 104 c/s, control signals appearing as discrete alterations in phase of the pulses, with respect to a second reference pulse train.

Changes in the tape recording system are matched by changes in the diffraction grating measuring system. A synchronously-driven spirally-ruled disk scans a linear grating fixed to the tool table and, by a photocell, provides a signal of frequency 104 c/s. Movement of the tool table causes phase displacement of this signal in relation to a second 104 c/s reference signal, produced by the disk scanning a second fixed grating. The phase displacement signals from the magnetic tape and electro-optical system are kept in step by the servomechanism. Hydraulic servos using electrohydraulic valves with ram or rotary actuators, replace the former electrical ones, and Ferranti have developed a standard servo unit, with a Moog valve, Lucas 3-b.h.p. motor, oil filter and gearbox.

Use of transistors in the pulse amplifiers has meant a reduction in the size of the control console, which comprises three control channel units (one for each dimension), a reference unit (used with manual control) spare units for maintenance, and a 24-V battery power supply.

The new equipment was demonstrated on a high precision profile milling machine, mainly used for cutting templates; a Hayes/Ferranti Tapemaster, a medium-sized vertical milling machine; and a larger Kerney and Trecker TF 415 vertical miller. The first two machines have been developed concurrently with the new numerical control system.

Ferranti's coordinate inspection machine, inspects work pieces to 0·0005 in.

Ferranti claim considerably improved performance from the new equipment and say it is unlikely to be changed materially for five years. Its price ranges from £7000 to £12,000, being about a 25% cheaper than the earlier equipment.

Numerical positioning equipment

The positioning equipment demonstrated is applicable to jig-borers, drilling machines, etc. Its price of about £2000 is claimed to be comparatively cheap for a system involving direct feedback from the work table.

It comprises a control console, with a new paper-tape reader on top of it. Coordinate and other machining information is recorded on the standard ⅞ in. tape, whose lines of punched holes are read in blocks to reduce the time required for passing information into the control circuits. These are transistorized and use printed wiring. The output from each control channel operates a 50 c/s induction motor, by either a high- or low-speed control clutch. The table moves quickly for the first part of its traverse, the slow clutch taking over to bring it to rest in its final position for the next operation, where the slides are automatically clamped.

As in the continuous-path equipment, diffraction gratings measure the position of the work-table, and a high-speed decimal counter connected to the grating records this with respect to a datum. The counter and tape-reader are checked continuously by a ternary logic circuit.

Automatic inspection

Perhaps the most exciting of the items demonstrated is the automatic inspection equipment. This consists of a vertical probe which is brought into contact with the machined part and whose x and y coordinate positions are recorded to an accuracy of 0·0005 in. on decimal counters. In effect, the equipment is the inverse of the static positioning equipment, without the servos or tape reader.

The probe is cantilever supported over the table carrying the machined part. Horizontally it can move up to 24 in. in the x direction and 15 in. in the y direction. Vertically it can move up to 10 in. but no measurement is made of its vertical position in the present equipment, which is normally manually set for each inspection pass.

Ferranti have three of these machines working in their own machine shops and they say that inspection time on the average is reduced to about one-quarter of that needed with hand methods.

The price of the inspection machine is about £2200.

£1600 controlled drill

EMI Electronics have developed a machine tool control system consisting of a Grimston drilling machine of up to

ROUND TABLE. This multi-station rotary transfer machine, by Centec Machine Tools Ltd., employs Maxam pneumatic cylinders and valves for control and operation of the sequencing and clamping systems. The machine drills seven holes ¼ in. dia at 7/16 in. centre distance in a small brass component, the production rate being 7½ sec. A 16 in rotary indexing table is used, which can index any angle divisible by three up to 180°. Accuracy of repetition is claimed to be ± 1·5 sec. and angular accuracy ± 5 sec.
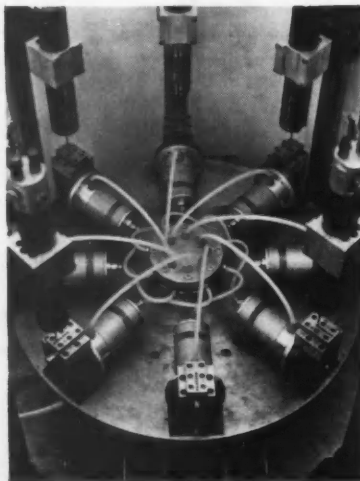
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¼-in. drill capacity (the chuck will accept a 1-in. drill, but the accuracy is lowered) controlled by 'Emicon' electronic positioning control. The measuring element is an Inductosyn of ± 0·0005 in. electrical accuracy. The system is fitted to a coordinate table (controlled axes, 10 in. by 10 in.), operating on recirculating ball slides, which is actuated hydraulically from a pneumatically-powered oil supply.

System and table form an integrated equipment for any drilling machine of suitable dimensions and spindle quality. The table is automatically locked as soon as the working position is reached and a signal may be provided to actuate the spindle feed when the table is in place. The machine can thus proceed automatically through a complete drilling programme.

Information can be fed into the control system in the form of 5-hole teleprinter tape, or alternatively may be set up on dials for manual operation. For tape control, ordinates of x and y are read alternately from the tape using a tape reader, the output of which operates the store unit to set up the desired position analogue voltages, the machine controls, and the automatic cycling facility.

——ELECTRICITY——

Fault location in high voltage lines

The North of Scotland Hydro-Electric Board has many 132 kV lines crossing difficult and mountainous terrain. If a fault occurs it becomes necessary for a linesman to patrol the line in search of it—a costly and time consuming process, particularly in winter. Faults fall broadly into three categories: latent—impaired ground clearance of a conductor for example, which will not cause flashover at normal voltages; sustained—a broken conductor, say, or a badly damaged insulator string; and transient—lines clashing in a high wind, for example.

Radar fault locators

Ferranti have been collaborating with the Board in seeking an electronic method of fault location, and have produced a 'radar type locator.' This is a pulse reflexion device, the reflexion being caused by any local variation in line characteristic impedance. The distance along the line to the fault is obtained from the time interval between pulse transmission and the reception of its echo.

Two fault locators have been developed: a d.c. type which is directly connected to a dead line and can, therefore, be used to detect sustained faults only; and an a.c. locator which is coupled to the live line through a suitable coupler (the coupling capacitor used with the carrier control system). The a.c. types,

Control desk and GEC Multiplex 'A' and 'B' centres for the RAF's 'Safeland' arrester barriers which are being installed at certain jet fighter aerodromes. Normally one A centre operates two B centres, one for the arrester barrier on each runway. The system is one in which a command signal from the A centre is received by the B centre controlling the barrier, the B centre then signalling the A centre that the command has been carried out

which are usually permanently sited at substations, can detect transient faults. The d.c. locators are portable and, although they have performed well under test, they are restricted in their application. Further development is, therefore, proceeding on an a.c. locator for both 132 kV and 275 kV lines.

The technique to be used for the detection of transient faults involves leaving the equipment normally in a standby condition and switching to the operating state in the few milliseconds between the detection of a fault, by the normal line protection equipment, and its clearance by the operation of the circuit breaker.

——AIRCRAFT——

RAF net runaways

In order to overcome the problem of the jet fighter aircraft which overshoots the runway because of wheel brake failure etc, the Royal Air Force is installing aircraft arrester barriers at certain aerodromes. The equipment is of Swedish design by Borgs Fabriks Aktiebolag and is known as the BEFAB 'Safeland' Overrun Barrier. The system employs a wide-mesh nylon net to catch the aircraft's wings and thus apply the braking action.
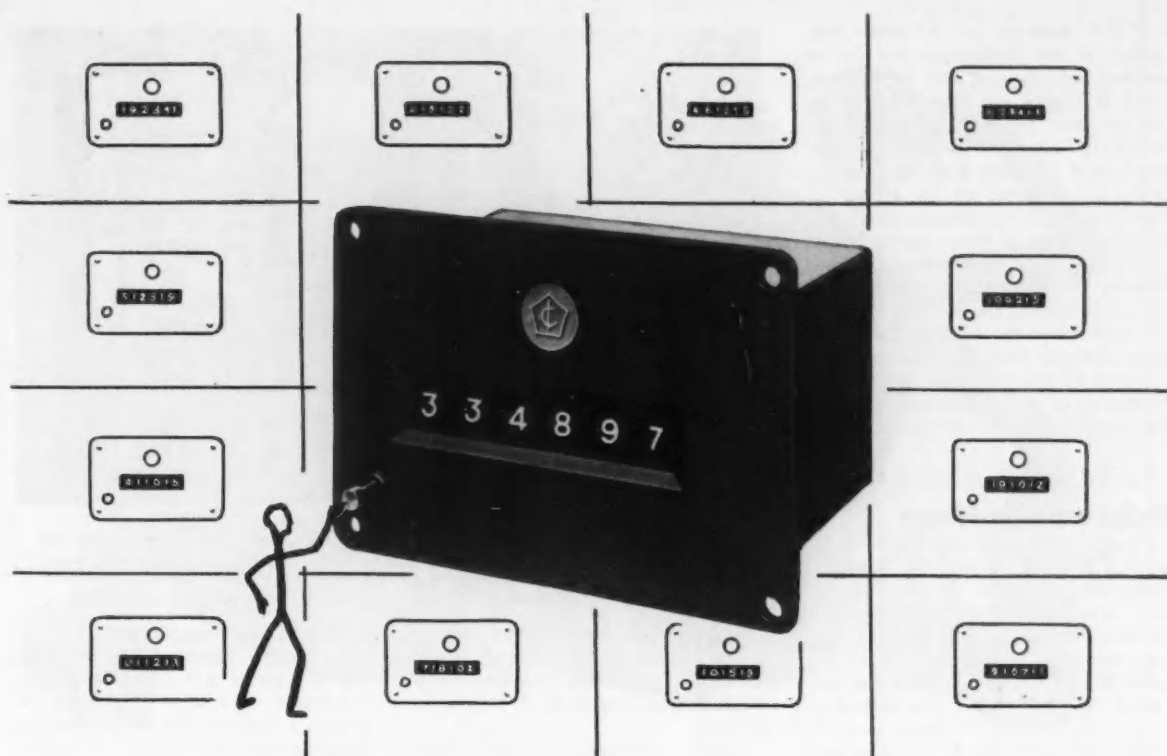
CONTROL understands that the RAF are
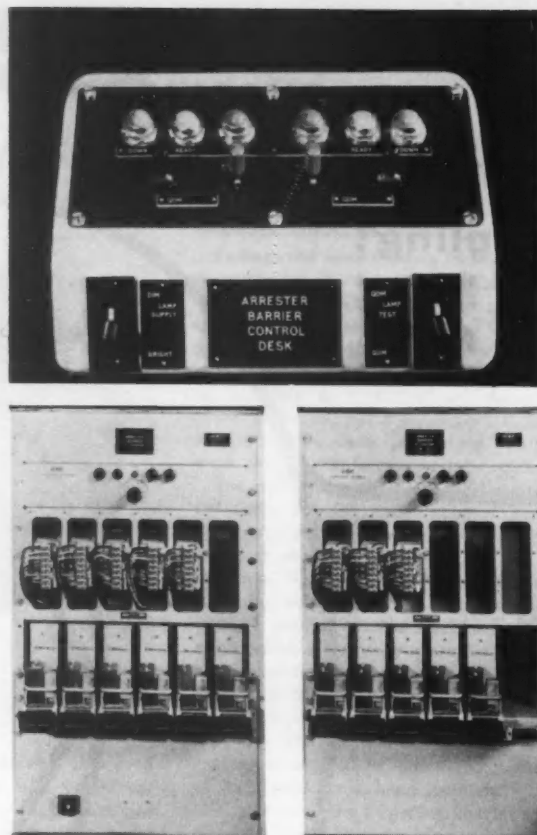
installing the types 4:3 and 6:3 'Safeland' barriers. According to the manufacturer's literature, these provide braking powers of 17,600 lb and 26,400 lb for aircraft in the 8000–17,800 lb and 9000–30,800 lb classes.

Basically a 'Safeland' installation comprises: a net, consisting of two horizontal cables and a series of vertical nylon ropes, this being connected at both ends to steel cables wound round brake drums; two stanchions to raise and lower the net and keep it extended; and pneumatic brake and anchor assemblies. When an aircraft strikes the net, shear pins disconnect the upper horizontal cable, so releasing the net from the stanchions, and the lower cable operates the brake drums.

'Multiplex' control

The RAF needed the barrier collapsed for normal use of the runway, but wanted to raise it rapidly if an aircraft was running out of runway, obviously landing at too high a speed, or if requested to by the pilot. It was decided to install GEC 'Multiplex' equipment so that the net could be operated from the control tower. A typical installation might consist of two barriers, one for each runway. The 'Multiplex' control for this comprises two 'B' centres (one per barrier) each consisting of three transmitters

and five receivers, an 'A' centre consisting of five transmitters and six receivers, and a control desk in the tower. Both B centres are operated from the control desk. The five signals from the tower are made up of barrier down—runway clear (1), stanchions up but net down (2), and net up (2). Hence the need for five A transmitters and five B receivers. Each B centre signals the A centre that these commands have been obeyed, the three signals being barrier down, stanchions up, and net up. The six receivers at the A centre handle the three channels from each barrier.

The RAF has informed CONTROL that a number of installations are operating satisfactorily and have proved their use.

—ATOMIC ENERGY—

Italian order for Plessey

Plessey Nucleonics seem to be doing well with their burst slug detection equipment for nuclear reactors. Recently, they have received an order from the Nuclear Power Plant Co. Ltd. for nine pneumatically-actuated ' mine ' precipitators for the detection of burst fuel elements, for the nuclear power station NPCC are building at Latina, some 30 miles south of Rome. It is also understood that Plessey Nucleonics have received an order for burst slug detection equipment for the UKAEA's advanced gas-cooled reactor project which is expected to start-up at Windscale in 1961.

In operation, the precipitator samples coolant gas from each of the fuel channels in the reactor. Should a fuel element can burst, fission products escape and contaminate the coolant system. Two of these fission products, krypton and xenon, are gaseous and subsequently decay into active solid daughter products which may be collected by electrostatic

PACE SETTING. Electronic Associates' PACE analogue computer installed at the UKAEA's Winfrith Heath Research Establishment. Costing about £100,000 the computer contains two separate 80-amplifier systems

SCHWEPPTRONICS—A Titromatic Analyser by Electronic Instruments in use on the tonic water line in Schweppes' Hendon bottling plant. The apparatus automatically and continuously monitors the tonic water stream by taking periodic samples and titrating these to a pre-set end point

precipitation on a wire. The wire is passed through a scintillation counter working in conjunction with a ratemeter which indicates the level of activity on the wire.

Similar precipitators have been approved for installation in the nuclear power station at Hinkley Point, which the English Electric-Babcock and Wilcox-Taylor Woodrow group are constructing for the CEGB. In this instance the output from Plessey Nucleonics' equipment is fed into numerous ratemeters and data processing equipment by Marconi Instruments.

— CONFERENCES —

Medical electronics

The Institution of Electrical Engineers is organizing two conferences of some control interest. The IEE's Electronics and Communications Section are organizing the Third International Conference on Medical Electronics in association with the International Federation for Medical Electronics. An International Scientific Exhibition on Medical Electronics is also planned. The intention is to bring together members of the medical and electrical engineering worlds so that each will gain a better understanding of the other's problems. The Conference is expected to take place in July 1960.

Nuclear electricity and instruments

The Measurement and Control Section and the Supply Section of the IEE are organizing a convention on the Impact of Nuclear Development on Electricity Supply and on Instrument Techniques,

to be held in London in 1961.

Among the subjects to be discussed will be present and future energy requirements in relation to energy resources available; economics; operating characteristics; the siting of nuclear power stations and its effect on system planning; health physics; radiation detectors; pulse circuits; nuclear measuring instruments, for research, processing control, and for prospecting and mining applications; instruments for nuclear reactors and associated plants; and data processing for nuclear applications.

The Organizing Committee would like to receive offers of papers for possible inclusion in the Convention.

CONTROL understands that the Federation of British Industries are considering holding a Conference on the general problems of nuclear generation during 1961, and that the IEE hope that there will be an appropriate coordination of arrangements where possible.

Conferences disappoint

As CONTROL goes to press, one conference on space is ending and the other starting. First, there was the Commonwealth Spaceflight Symposium which was sponsored by the British Interplanetary Society, the Canadian Astronautical Society, the Indian Astronautical Society, and the South African Interplanetary Society. From our viewpoint a disappointing conference. Control would appear to be a fundamental of this somewhat blue-sky subject but little or no mention of any practical device was made.

The 10th Congress of the International Astronautical Federation although much more comprehensive, appears to suffer from much the same lack of realism.

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——— BUSINESS ———

Kent's satisfactory year

George Kent had a satisfactory year's trading despite some difficulties, according to Commander P. W. Kent, the chairman, in his report for the year ending April 4 which he presented on August 28. Their steering gear interests (they market through Cam Gears Ltd) had 5% increased sales, and the outlook continues good. They are jointly interested with Cam Gears in Hydrosteer Ltd. which is producing power-assisted steering gears 'on a profitable basis.'

Sales of instruments and meters, were down by 6%, this being due to Kent's dependence on capital schemes which were hit by past restraint in the national economy and restricted purchasing power in the export markets. However, ' orders in this division have improved notably in the last few months.' Kent's orders for equipment for large power stations decreased during the year, but orders in such fields as water and sewerage, metallurgical, nuclear power and industrial power plants increased substantially. Orders for their new electronic instrument range are developing and they have high hopes for additional sales of this equipment in the near future.

The parent company's profit for the year was down on the preceding year— £450,586 compared with £525,654 last year—but net profit went up from £265,749 to £278,586.

Gallenkamp-Towers merger

A. W. Rundle, Managing Director of A. Gallenkamp has informed CONTROL that ' An agreement in principle has been concluded whereby it is intended that A. Gallenkamp & Co. Ltd. will acquire the business of J. W. Towers & Co. Ltd.' Towers will continue to trade as a separate company and J. S. Towers will continue as Managing Director while the interests of the two firms are coordinated.

RADIO ASTRONOMY

Australia's radio telescope

The 210-ft radio telescope which is to be erected for CSIRO (Commonwealth Scientific and Industrial Research Organisation) at Parkes, New South Wales. Australia, will be controlled by a servo system developed by the Servo Group of AEI Electronic Apparatus Division. The moving portions of this instrument, only slightly smaller than the 250-ft telescope at Jodrell Bank, will weigh approximately 800 tons but will be controlled to considerably higher accuracies.

In addition to the servo control, AEI, who carried out a design study on the mechanical elements of the servo drive, will supply all electrical equipment associated with the telescope, with the exception of that for the master equatorial unit, its error detector and the telescope control desk, which are being supplied by the Berlin astronomical telescope firm of Askania-Werke AG.

AEI are providing an audio-frequency intercommunication system between the master station at the control desk and eleven out-stations ten of which are on the telescope itself. Each out-station will be able to communicate with each other as well as with the master station. The controller at the master station can obtan immediate communication to any out-station by cutting-in. Several out-stations as well as the master station, if necessary, can be interconnected to enable people at the various points selected to converse with one another.

The main contractor is Maschinenfabrik Augsburg-Nürnberg who will manufacture the structure.

Briefs

Texas Instruments' new plant at Bedford will total 125,000 ft² and is due to be occupied in the autumn of 1960.

Xerography. Ferranti have ordered a Rank Xeronic, 3000 line/min, output printer for use with digital computers.

Aircraft instrument repair and overhaul service has been organized by Smiths at their Bishops Cleeve, Cheltenham, factory. Three maintenance schemes are operating: an exchange scheme paid for at a rate per flying hour; a one-for-one exchange scheme; a normal service scheme with a four-week turnround.

Saturable core reactor, the basis of the stepless temperature controller, is to be the subject of one-day courses. Details: James Hartnett, West Instrument Ltd., 52 Regent Street, Brighton 1, Sussex.

London Transport's Research Dept is to be housed in a new two-storey 26,000 ft² Central Laboratory at Chiswick.

Kodak have ordered an Emidec digital computer from EMI Electronics for accounting and stock recording.

Electrical connectors by the Continental Connector Corp. of New York are to be manufactured by Ultra Electric for sale in the UK, the Commonwealth, Europe and Asia.

Control valves and associated equipment in the ' Super 70 ' range of Black, Sivalls and Bryson Inc., USA, are to be manufactured by Cockburns Ltd. of Glasgow and their subsidiary Cockburns (Nederland) NV in Schiedam, Holland.

LOOKING AHEAD

WEDNESDAY 2—WEDNESDAY 9 SEPTEMBER
Annual Meeting British Association for the Advancement of Science. York. Details: The Secretary, 18 Adam Street, Adelphi, WC2

THURSDAY 3—SATURDAY 19 SEPTEMBER
Scottish Industries Exhibition, Kelvin Hall, Glasgow

MONDAY 7—SUNDAY 13 SEPTEMBER
SBAC Flying Display and Exhibition. Farnborough

SATURDAY 12—MONDAY 21 SEPTEMBER
European Machine Tool Exhibition. Paris

WEDNESDAY 16—FRIDAY 18 SEPTEMBER
General Meeting of the International Federation of Automatic Control. Chicago. Details: The Secretary, IFAC, VDI/VDE-Fachgruppe Regelunstechnik, Prinz-Georg-Strasse 77-79, Düsseldorf, Germany

MONDAY 20—FRIDAY 25 SEPTEMBER
World Progress in Instrumentation Conference. Chicago. Details: Instrument Society of America, 313 Sixth Avenue, Pittsburgh 22, Pennsylvania, USA

OCTOBER—SEPTEMBER 1960
Information Engineering and Theory of Electrical Machinery (which includes sections on automatic control systems). Details: The Graduate Course Supervisor, Electrical Engineering Dept, The University, Edgbaston, Birmingham 15

MONDAY 5 OCTOBER—FRIDAY 8 JULY 1960
Postgraduate Course in Control Engineering. Applications to The Warden, College of Aeronautics, Cranfield, Bucks

TUESDAY 6 OCTOBER—JUNE 1960
Postgraduate Course in Control Engineering. Details: The Secretary, Cambridge University Dept of Engineering, Trumpington St, Cambridge

THURSDAY 22—SATURDAY 24 OCTOBER 1959
Eighth Annual SIMA Convention, Brighton

LOOKING FURTHER AHEAD

TUESDAY 10—SUNDAY 15 NOVEMBER
International Exhibition of Laboratory, Measurement and Automation Techniques in Chemistry. Basle. The Association of Swiss Chemists in collaboration with the Swiss Association of Automation will hold a scientific congress covering the same fields

MONDAY 16—FRIDAY 20 NOVEMBER
The Fifth International Automation Exposition. New York

TUESDAY 5—THURSDAY 7 JANUARY 1960
Symposium on recent mechanical engineering developments in automatic control. Details: The Secretary, The Institution of Mechanical Engineers, London

MONDAY 11—WEDNESDAY 13 JANUARY 1960
6th National Symposium on Reliability and Quality Control in Electronics. Washington. Details: R. Brewer, General Electric Co. Ltd., Wembley, Middlesex

WEDNESDAY 10—FRIDAY 12 FEBRUARY 1960
Solid State Circuits Conference. Philadelphia. Details: The Chairman, 1960 Solid State Circuits Conference, General Electric Co., Electronics Laboratory, Electronics Park, Syracuse, New York, USA

THURSDAY 21—TUESDAY 28 APRIL 1960
American Society of Tool Engineers' 1960 Tool Show and Convention. Detroit

MONDAY 22—FRIDAY 26 FEBRUARY 1960
1st Engineering Materials and Design Exhibition. Earls Court

FRIDAY 10—SUNDAY 26 JUNE 1960
British Exhibition USA. New York. Details: British Overseas Fairs Ltd., 21 Tothill Street, SW1
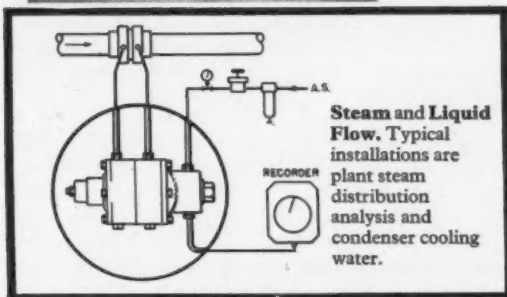
SATURDAY 25 JUNE—TUESDAY 5 JULY 1960
Moscow Congress for Automatic Control. Details: International Federation of Automatic Control, Prinz-Georg-Strasse 79, Düsseldorf, Germany

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For your bookshelf

'Automation' or 'mechanization'

Automation in Production Engineering by J. A. Oates. *Newnes.
1959. 326 pp. £2 5s.* ★ 241

There appear to be two distinct phases in the development of
automation. The first can probably be described as 'mechanical
automation,' where the developments are essentially towards
the progressive integration of mechanical machining and form-
ing processes, and which has its ultimate expression in the
transfer line. The second and later phase, which may perhaps
be best described as 'electronic automation,' is concerned
essentially with the application of advanced instrumental tech-
niques and data-handling techniques. This phase often involves
computers, and is perhaps of particular importance to the pro-
cess industries.

This book is primarily concerned with mechanical automa-
tion although the last quarter of the book is on electronic
machine tool control; the book is devoted exclusively to the
manufacturing as distinct from process industries. Within these
limitations it is an excellent handbook of its type. The subject-
matter covers the use of electrical, pneumatic and hydraulic
control equipment for position control, particularly as applied
to mechanical handling. The book goes on to elaborate the
development of automatic machining devices, including copying
lathes, gear hobbing and shaving machines, and includes a
description of various British automatic gauging and mechani-
cal inspection systems. There is an excellent discussion of basic
systems of machine-shop automation, followed by chapters on
the design of rotary and in-line transfer machines.

This book can be particularly recommended to electronic
control engineers who may wish to acquire a background in
advanced mechanization techniques in order to assess the fur-
ther scope for electronics. They may well be surprised at the
extent to which pneumatic and hydraulic circuits have been
developed for logical control functions.

There are two outstanding omissions in the book which one
trusts will be corrected in a second edition. One is a description
of some of the automatic electronic inspection equipments
developed in the USA, and other is an account of the use
of solid-state devices, including transistors and phototransistors,
for logical control. **D. B. FOSTER**

Flip-flop : bow-wow

Multivibrator Circuits by A. H. Bruinsma. *Cleaver-Hume Press.
1959. 65 pp. 9s. 6d.* ★ 242
Practical Robot Circuits by A. H. Bruinsma. *Cleaver-Hume
Press. 1959. 125 pp. 17s. 6d.* ★ 243

'Multivibrator Circuits' is a lucid account of the working of
some multivibrator and gating circuits. It is a popular non-
mathematical presentation in which exponential functions, for
instance, appear only graphically. The only prior knowledge
assumed is of resistance, capacitance and the thermionic valve.
For each of the main modes of operation (free-running, mono-
stable and bistable), the author describes only one type of
circuit, except for brief mention of variations using pentodes.
Phantastrons, etc., are not included. However, the circuits
treated are widely applicable, and practical details such as
synchronization and factors affecting pulse shape are adequately
dealt with, as is the use of bistable circuits for binary counting.
Component values are not shown, but can be found in practical
circuits in the second book.

The purpose of 'Practical Robot Circuits' is rather obscure.
After stating that the term 'robot' includes such diverse mech-
anisms as guided missiles, self-opening doors and accounting
machines, the writer describes two examples in considerable

detail. The first is an electronic dog, which steers itself towards
a source of light or sound, wags its tail if its name is called,
barks at objects encountered and licks a warm object presented
to it. The second is a machine for playing noughts and crosses.
The descriptions are not quite detailed enough to let a reader
build similar robots without some ingenuity, though complete
circuits are shown for the dog. Multivibrators are not often
seen in battery-valve versions, and the book could be a useful
source of practical forms. An interesting feature is an electronic
stabilizer used for one of the battery voltages. In fact, the main
usefulness of this book seems to be to provide practical ex-
amples of various electronic circuits in an entertaining context.
A. M. ANDREW

Unbiased, but a little overwhelming

Electronic Digital Computers by Charles V. L. Smith. *McGraw-
Hill. 1959. 443 pp. £4 13s.* ★ 244

Books about computers fall into two classes; those by mathe-
maticians and those by engineers. Inevitably each tends to write
for his own kind. Absence of this bias is rare, but this book,
although on the face of it written by an engineer, is perhaps
an exception, being concerned equally with the fundamental
logic and its engineering representation, as well as the philo-
sophy of design. By this latter is meant the basic axioms (con-
sciously or unconsciously) assumed by the designer.

Mr. Smith, who is head of the Computing Laboratory,
Aberdeen Proving Ground, USA, sets out to explain how
computers work. The introductory chapters are on digital com-
puter arithmetic, instruction codes and general ideas about
systems. Then there are chapters on basic logical elements,
storage elements and on combinations of these into registers,
counters, adders and structures of still more complex logical
function. Two further chapters on large storage systems are
followed by functional analyses of the other main organs of
the computer. The last chapter describes a number of super-
high-speed computers now being designed and built in the
USA.

The author quotes, with references, engineering and logical
design details of many American and other computers. The
text, diagrams, printing and make-up are of the high standard
one expects from its publishers; there are name and subject
indices. The great mass of detailed, exact and up-to-date in-
formation given will be invaluable to the specialist designer;
to the control engineer, seeking an introduction to the pattern
of behaviour of the whole computer or to its design philoso-
phy, it may seem a little overwhelming. Dr. Wilkes' earlier
book* should perhaps be read first. **J. M. M. PINKERTON**
* 'Automatic Digital Computers' (Methuen, 1957)

Books Received

Canadian Conference for Computing and Data Processing. *Toronto
University Press. Oxford University Press: London. June 1959.
383 pp. £2* ★ 245

Operations Research: Problems & Methods by M. Sasieni *and
others. John Wiley: New York. Chapman & Hall: London. 1959.
316 pp. £4 2s.* ★ 246

Linear Network Analysis by S. Seshu *and* N. Balabanian. *John
Wiley: New York. Chapman & Hall: London. 1959. 571 pp.
£4 14s.* ★ 247

Control Engineering by G. J. Murphy. *D. Van Nostrand. August
1959. 385 pp. £2 16s.* ★ 248

Automation in Production Engineering by J. A. Oates. *George
Newnes. 1959. 326 pp. £2 5s.* ★ 249

Conductance Design of Active Circuits by Keats A. Pullen Jr.
*John F. Rider: New York. Chapman & Hall: London. 1959.
330 pp. £4* ★ 250

Dictionary of Guided Missiles and Space Flight *edited by Grayson
Merrill. D. Van Nostrand. June 1959. 688 pp. £6 11s. 6d.* ★ 251

Properties, Physics and Design of Semiconductor Devices by J. N.
Shive. *D. Van Nostrand. 1959. 487 pp. £3 13s.* ★ 252

★ Tick the relevant number on the reader information card for further inform-
ation on any book reviewed above.